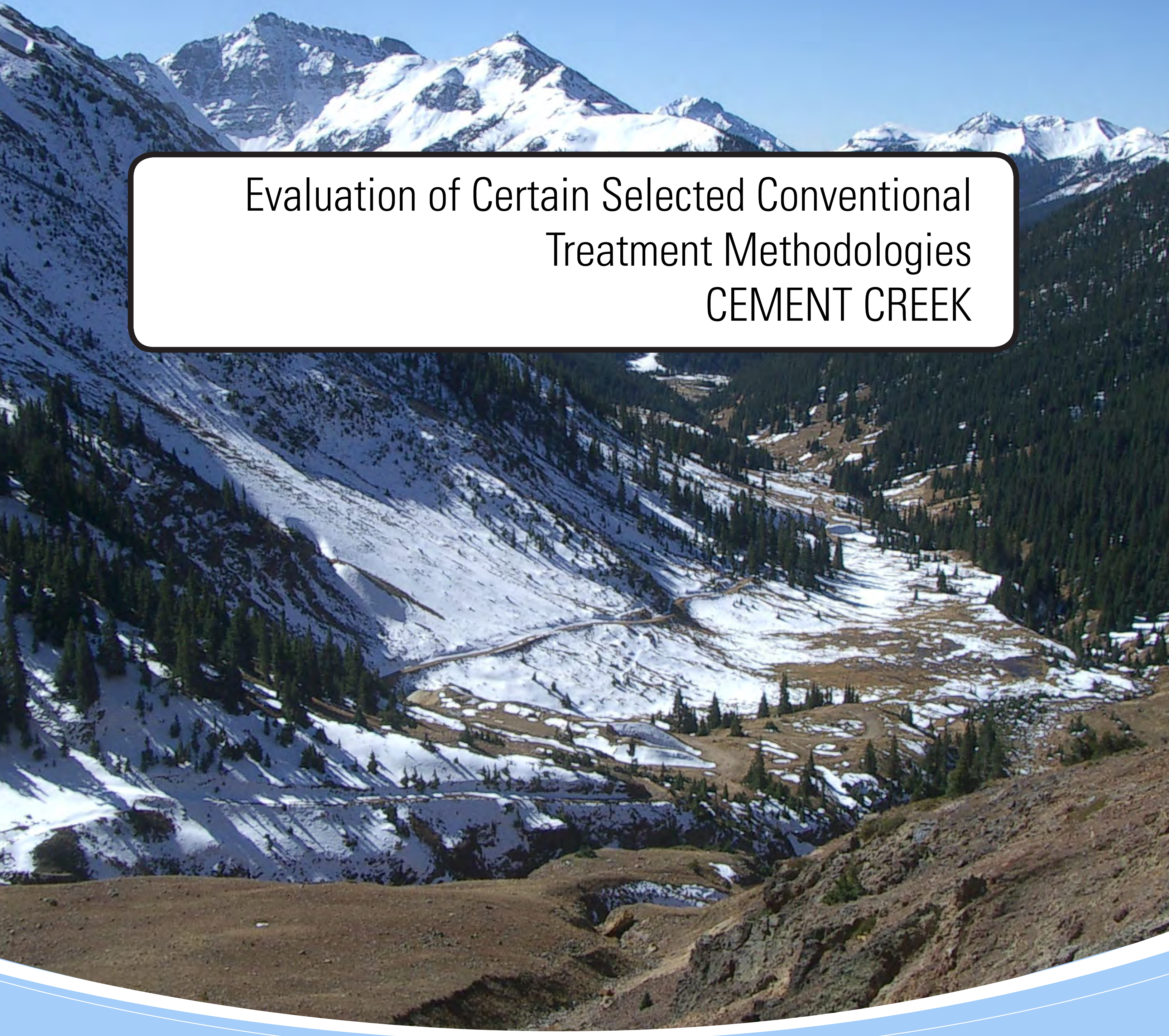
Evaluation of Certain Selected Conventional Treatment Methodologies
CEMENT CREEK



July 2012

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MWH
BUILDING A BETTER WORLD

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EXECUTIVE SUMMARY

The Cement Creek drainage is located in the Upper Animas Mining District in Southwest Colorado. Cement Creek is a tributary to the Animas River and joins the Animas River within the City of Silverton, Colorado. The Cement Creek and adjacent drainages (i.e., Mineral Creek, Animas River, etc.) in the upper Animas Mining District are highly mineralized and have been subjected to significant mineral evaluation and development since the mid-1800s. The Cement Creek drainage has sulfide mineralization and while pre-mining water quality data is unavailable, water quality in upper and lower Cement Creek likely was impacted by the native geologic conditions even before mineral development occurred in the area.

From 1978 through 2002, Sunnyside Gold Corporation (SGC) and its predecessors operated a water treatment plant (WTP) at Gladstone. Starting in 1996, the WTP directed up to 4.5 cfs of the Creek's flow through a lime treatment process that increased the water's pH to precipitate metals of concern (copper, zinc, cadmium, iron, etc.). The WTP was operated by SGC under a permit from the State of Colorado until 2003. In 2003 following completion of the Terms and Conditions of a Consent Decree with the State of Colorado Department of Public Health and Environment, SGC was relieved of further environmental mitigation responsibilities in the area. At that time, Gold King Mines Corporation assumed the operation of the WTP and the associated permit. Gold King operated the facility into 2004 until it was decommissioned. The settling ponds were reclaimed in 2006.

Since 2004, noticeable changes in water quality have occurred in both Cement Creek and the upper Animas River below its confluence with Cement Creek. This Report evaluates certain selected conventional water treatment methodologies and was developed to provide a base case water treatment alternative against which other methodologies and approaches could be measured and assessed to address concerns regarding water quality in the upper Animas River. As a result of Logsdon's water quality study (Mass Loading Analysis of upper Animas River at Water Quality Station A-72, 2012) and discussion with SGC, it was determined that it would be useful to evaluate the collection and treatment of specific known mine adit drainages as well as the potential to treat all or part of the flow from upper Cement Creek.

This evaluation involved the following primary activities:

- Review and analysis of existing water quality data and reports relative to the upper Animas River drainage
- Initial screening of eight known water treatment methodologies
- Selection of four conventional treatment methodologies for bench-scale testing and evaluation using upper Cement Creek water. The selected methodologies are:
    1. Lime - Hydroxide precipitation
    2. Ferric Chloride and Lime - Hydroxide precipitation followed by enhanced coagulation
    3. Sulfide and Lime - Metal sulfide precipitation
    4. Oxidation Co-precipitation - Co-precipitation using ferric and manganese oxidation
- Determination of "best apparent" treatment methodology from the bench-scale testing to carry forward in the evaluation
- Development of five conceptual treatment alternatives (facility designs) for evaluation that would utilize the "best apparent" treatment methodology; the five alternatives developed are:
    1. Alternative 1 - Adit collection and partial Cement Creek flow treatment with mechanical solids settling and "dry" sludge disposal (1,000 gpm capacity).
    2. Alternative 2 - Adit collection and partial Cement Creek flow treatment with pond settling of solids and "wet" sludge disposal (1,000 gpm capacity).
    3. Alternative 3 - Cement Creek flow treatment, up to 2,000 gpm, with mechanical solids settling and "dry" sludge disposal.
    4. Alternative 4 - Cement Creek flow treatment, up to 2,000 gpm, with pond settling of solids and "wet" sludge disposal.
    5. Alternative 5 - Adit collection and treatment with direct filtration of solids and "dry" sludge disposal (1,000 gpm capacity)
- Screening and evaluation of the five treatment alternatives using eight non-financial screening criteria as follows:
    1. Treatability (effectiveness of metal removal)
    2. Reliability

3. Practicality
4. Operability
5. Flexibility
6. Removal/Disposal
7. Infrastructure requirements
8. Environmental considerations

- Development of preliminary capital cost (CAPEX) estimates
- Development of preliminary operating cost (OPEX) estimates
- Comparison of alternatives and statement of opinions

Based on the bench-scale testing of the selected treatment methodologies, conventional lime precipitation stands out as the “best apparent” treatment methodology and is very effective at reducing metal loads in upper Cement Creek source water.

Five conceptual treatment alternatives were then developed, incorporating the lime precipitation methodology, and analyzed using the eight non-financial screening criteria discussed above. The screening criteria and results of the screening exercise are shown in the table below.

Table E1

Non-Financial Screening of Alternatives

Alternatives	**Screening Criria**								
	Treatability	**Reliability**	**Practicality**	**Operability**	**Flexibility**	**Removal/Disposal**	**Infrastructure**	**Environmental**	**Total Score**
Alternative 1 Adit collection and partial Cement Creek flow treatment with mechanical solids settling and "dry" sludge disposal (1,000 gpm capacity).	5	4	5	4	5	5	4	5	37
Alternative 2 Adit collection and partial Cement Creek flow treatment with pond settling of solids and "wet" sludge disposal (1,000 gpm capacity).	5	3	4	3	5	4	3	3	30
Alternative 3 Cement Creek flow treatment, up to 2,000 gpm, with mechanical solids settling and "dry" sludge disposal.	4	4	5	4	5	5	4	5	36
Alternative 4 Cement Creek flow treatment, up to 2,000 gpm, with pond settling of solids and "wet" sludge disposal.	4	3	4	3	4	4	3	3	28
Alternative 5 Adit collection and treatment with direct filtration of solids and "dry" sludge disposal (1,000 gpm capacity)	3	3	4	3	4	4	4	4	29

Screening Criteria Rating

Best Meets Results........................5
Meets Results................................4
Partially Meets results...................3
Does Not Meet Results..................2
Negative Impacts...........................1

The estimated capital and annual operating costs for each of the five evaluated alternatives are shown in the tables below.

Table E2

Capital and Annual Operating Cost Estimates for Alternatives

	Cost Estimates, $US	
Alternative	**Capital Cost**	**Operating Cost, Annual**
1	$ 6,524,000	$ 910,000
2	$ 5,960,000	$ 876,000
3	$ 6,407,000	$ 1,440,000
4	$ 5,573,000	$ 1,442,000
5	$ 4,537,000	$ 930,000

Based upon non-financial screening criteria, Alternatives 1 and 3 are superior to the others. Of these two, Alternative 1, due to its lower annual operating costs, is financially superior and provides the best base case alternative against which other methodologies and approaches could be measured.

1.0 INTRODUCTION

This Report evaluates certain selected conventional water treatment methodologies and was developed to provide a base case water treatment alternative against which other methodologies and approaches could be measured and assessed to address concerns regarding water quality in the upper Animas River. This evaluation is focused on conventional treatment alternatives applied to upper Cement Creek (near Gladstone) as a major tributary and metal load contributor to the Animas. The Report includes estimates of the capital and operations cost for each of the analyzed alternatives.

1.1 Background

The Cement Creek drainage is a tributary to the Animas River above Mineral Creek. While the drainage area is relatively small (13,100± acres), its topography is relatively steep sided and subject to rapid spring runoff conditions. Cement Creek between Gladstone and the confluence with the Animas River near Silverton is relatively undeveloped except for limited recreation and historic mining activities. The elevation of the drainage ranges from 9,300 to 11,500 feet in the general area (Silverton to Mogul Mine complex) considered in this report.

There are numerous mining related features that discharge water to Cement Creek. These features include four water producing mine adits/portals that are considered to be significant sources of water quality concern for the purpose of this report. They are the American Tunnel, Gold King Mine adit, Mogul Mine adit, and Red Bonita Mine adit. In addition, there are numerous creeks, gulches and ephemeral drainages that discharge to Cement Creek along its entire length. Many of these tributaries contain historic mines, prospects and other mine related workings that can affect water quality in Cement Creek. The Cement Creek drainage is believed to have had historic natural water quality degradation resulting in low pH and elevated dissolved mineralization in the water as a result of the native geology of the area. This condition is similar to other areas of the country that have concentrated sulfide mineralization that is exposed by weathering influences, high precipitation and mountainous topography.

From the available water data, noticeable changes in water quality began occurring in the 2003 – 2004 time period. Prior to that general period, in-stream metal loading, in terms of key metals of interest (zinc, copper, cadmium, etc.), was lower by as much as an order of magnitude at the CC-48 monitoring station (Figures 1A & 1B), located above the confluence of the upper Animas River and Cement Creek.

There was a water treatment plant (WTP), located near Gladstone, that was operated from 1978 to 2003. The WTP was successful in providing the desired water quality results in Cement Creek (CC-48) and the upper Animas River (A-72). Thus, information from that facility is a useful starting point for this evaluation.

From mid-1996 through 2003 when the Gladstone treatment plant was in operation, as much as 1,600 gpm of Cement Creek flow was diverted for treatment at the facility. The treatment plant increased the pH to 9 or higher using slaked lime (an average of 370± mg/L of lime was added based upon operator recollection). Lime precipitated metal solids were allowed to settle within four flow-through earthen settling ponds prior to discharge back to Cement Creek. The facility was relatively simple and, other than the addition of a flocculant (to improve pond settling), no other chemicals were used for the treatment of target metals or to remove dissolved and suspended solids. Information regarding the individual sources (Cement Creek and American Tunnel) that were diverted for treatment and the treatment plant effluent water quality was made available for use in this study. Influent water quality monitoring was maintained on a monthly basis from individual grab samples and effluent grab samples were collected weekly. The numerical discharge information for the operating treatment facility was limited to zinc, copper, lead, mercury, TSS, and pH although other parameters were monitored on a periodic basis (aluminum, manganese and iron). Discharge limits for the facility were established by the Colorado Department of Public Health and Environment (CDPS-CO-0027529) and were essentially the same limits as the federal “best available technology” limits (BAT) for a mining/processing facility at the time.

There were no other specific numerical discharge limits beyond the typical BAT requirements for the treatment plant’s discharge effluent concentration (except pH range 7.0 to 10.0) for the

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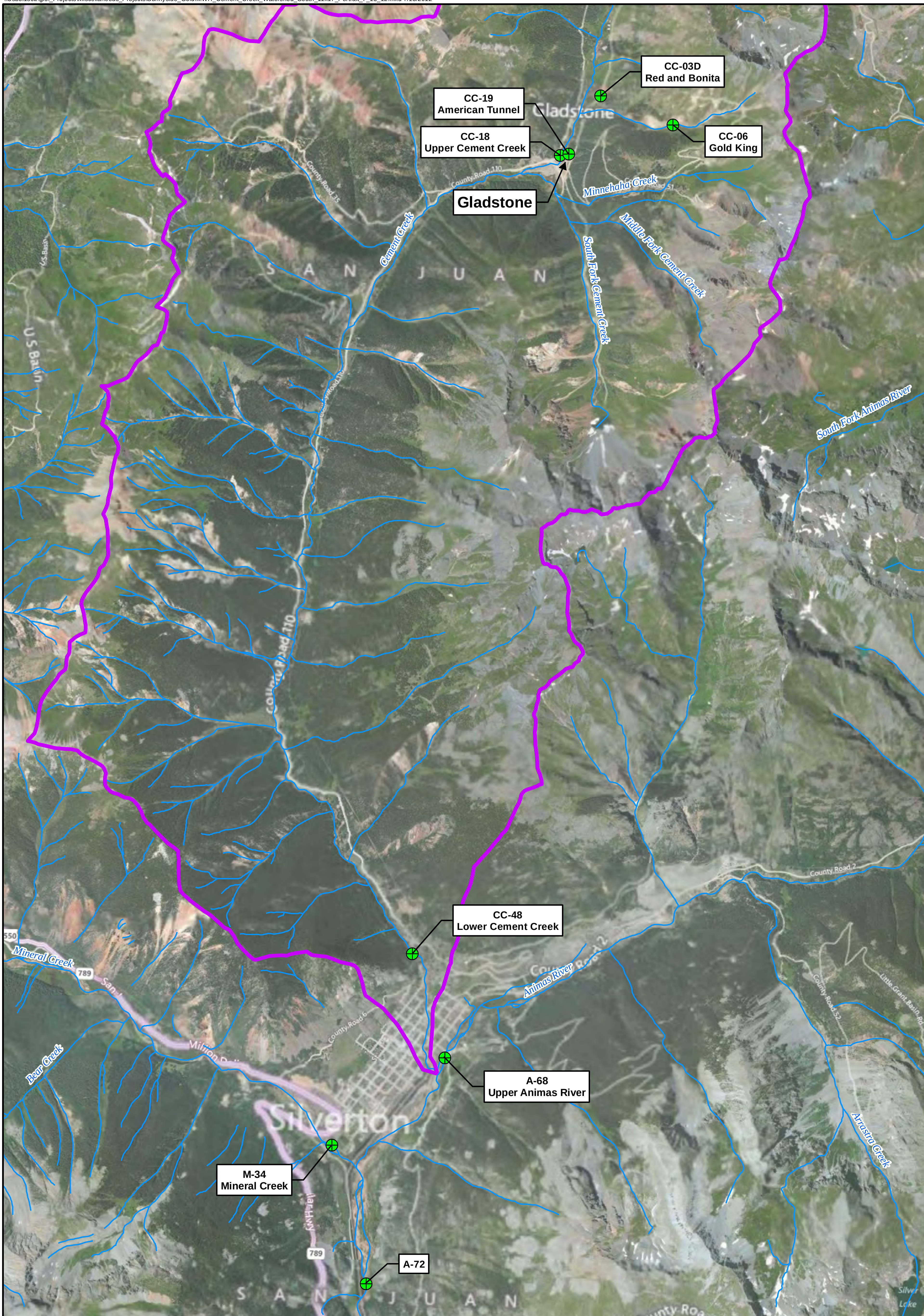

LEGEND

Monitoring Site

Streams

Cement Creek Watershed (13,060 Acres)

N
W E
S

0 1,500 3,000 4,500 6,000
SCALE IN FEET

TITLE:
Monitoring Site Location Map

PROJECT:
Sunnyside Mine / Cement Creek

REFERENCE(S):
Spatial Reference: NAD 1983 UTM Zone 13N

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FIGURE
1A

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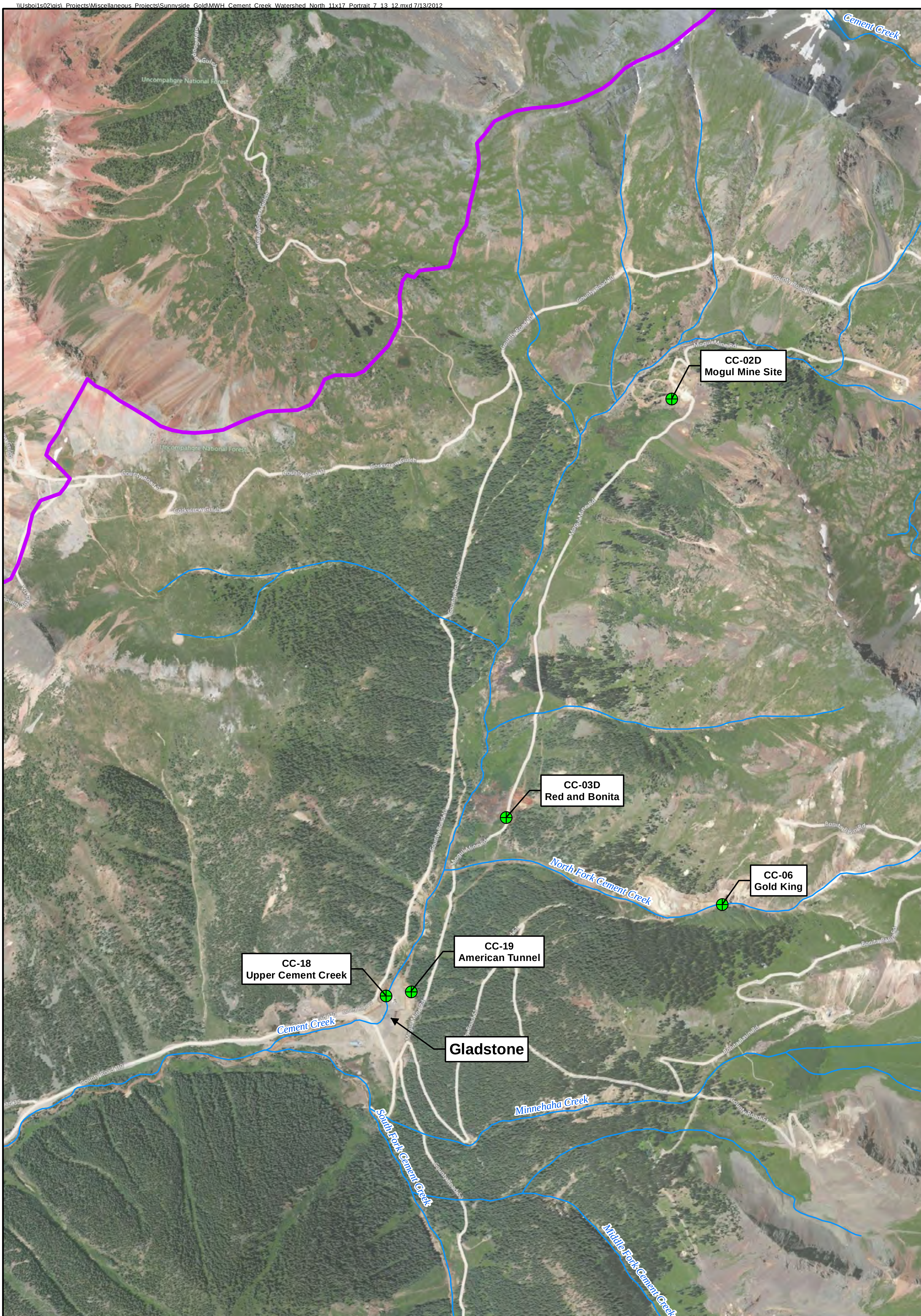

LEGEND

- Monitoring Site
- Streams
- Cement Creek Watershed (13,060 Acres)

N W E S

0 500 1,000 1,500 2,000

SCALE IN FEET

TITLE:

Monitoring Site Location Map

PROJECT:

Sunnyside Mine / Cement Creek

REFERENCE(S):

Spatial Reference: NAD 1983 UTM Zone 13N

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FIGURE

1B

period of record (1996 – 2003), although TDS was to be monitored and reported monthly. Flows (treated effluent) ranged seasonally from a high of approximately 1,600 gpm down to 360 gpm according to the available information.

Recent (2009 – 2011) water quality information for Cement Creek (CC-48) above the confluence with the upper Animas River is provided in Table 1. Copper concentration averaged 130 µg/L with a maximum value of 255 µg/L. Zinc had an average of 1,997 µg/L and a maximum month value of 2,880 µg/L during this approximate 40-month period of record. The general indication is that both the copper and zinc concentration began to increase statistically near the beginning of 2003.

Table 1

Lower Cement Creek Location of Sample CC-48

DATE	cfs FLOW_	PH	mg/L Ca	mg/L Mg	mg/L Na	mg/L K	mg/L SO4	mg/L TDS	µg/L Al	µg/L Cd	µg/L Cu	µg/L Fe	µg/L Mn	µg/L Pb	µg/L Zn
3/3/2009	12.00	3.27	200.00	11.00	4.00	3.00	688	904	8,150	6.200	129.00	12,600	5,080	20.000	2,560
3/4/2009		3.86	179.04	10.69	4.39	1.93	606	862	7,471	5.750	140.90	9,110	4,988	20.000	2,391
4/6/2009		3.36	177.64	9.93	4.14	1.67			8,273	4.790	124.30	15,350	4,288	20.000	2,096
5/13/2009	292.00	6.30	25.76	2.10	1.43	0.59	79	136	666	2.210	56.90	1,830	719	10.000	621
5/19/2009	227.00	5.40	28.60	2.37	1.26		86		751	2.100	56.30	2,000	766	0.000	611
6/2/2009		4.50	46.56	3.55	1.23	0.68			1,902	2.630	85.10	3,850	1,245	20.000	854
6/16/2009	58.00	4.29	67.60	4.82	2.26		199	320	2,890	3.400	90.60	3,090	1,770	10.000	1,080
7/8/2009	43.00	4.94	85.18	5.52	1.98	0.95	287	449	3,244	3.710	103.50	3,160	2,258	10.000	1,334
7/14/2009	28.00	3.95	106.00	6.99	3.03	1.23	279	500	4,050	4.600	110.00	3,670	2,830	10.000	1,620
8/12/2009		3.45	158.93	9.89		1.70			6,779	5.800	255.30	6,660	4,351	20.000	2,455
8/18/2009	18.00	3.51	172.00	10.45	4.27	1.93	541	870	7,045	6.550	222.50	7,760	4,840	20.000	2,685
9/16/2009	17.00	3.94	159.33	10.30	3.83	1.91	535	745	7,038	6.280	224.60	5,350	4,402	20.000	2,557
9/22/2009	18.00	3.65	171.00	10.40	4.67	1.92	507	870	6,930	6.600	189.00	9,530	4,920	10.000	2,570
10/5/2009		3.31	160.51	10.72	3.81	1.83			5,985	6.320	213.20	8,720	5,024	20.000	2,561
11/4/2009	18.00	2.80	187.00	11.00	4.00	2.00	619	846	7,060	6.200	165.00	9,970	4,920	10.000	2,490
11/5/2009		3.47	11.60	1.78	1.31	0.63			0	0.000	1.20	60	0	0.000	0
11/17/2009	15.30	3.50	180.00	11.00	5.57	2.12	450	890	7,850	6.400	152.00	1,160	5,270	20.000	2,650
12/1/2009		3.36	22.27	3.50	2.98	0.94			21	0.210	1.10	130	8	0.000	0
2/17/2010		3.50	208.50	11.85	5.21	2.02	604	960	8,420	5.450	118.50	13,250	5,275	10.000	2,665
3/2/2010		3.43	201.13	12.37	4.70	2.22			8,075	5.170	132.90	12,840	5,346	10.000	2,676
3/17/2010	13.70	3.42	198.00	11.20	5.76	2.10	529	940	7,820	5.300	109.00	9,640	5,200	10.000	2,600
4/6/2010		3.50	194.63	11.32	4.59	2.17			7,996	5.500	128.70	13,630	5,349	20.000	2,681
4/13/2010	26.40	3.93	108.00	6.99	3.52	1.29	355		4,830	4.900	110.00	8,540	3,005	10.000	1,575
5/5/2010	40.00	4.15	75.46	5.07	2.08	1.07	246	351	3,166	4.000	92.70	6,370	2,163	10.000	1,414
6/2/2010	137.00	5.15	30.64	2.43	1.31	0.54	104	170	983	2.190	73.00	2,380	825	10.000	664
7/8/2010	25.00	3.05	108.49	6.94	2.78	1.11	370	521	4,320	4.510	123.00	3,070	2,700	20.000	1,548
7/13/2010	21.00	3.57	125.00	8.04	3.45	1.52	374	620	5,090	4.400	118.00	4,300	3,280	20.000	1,800
8/10/2010		3.57	125.60	8.66	2.78	1.43			5,942	5.570	184.10	5,030	3,491	20.000	2,026
9/9/2010	17.00	3.04	155.08	9.19	3.90	1.88	542	807	6,544	5.680	179.70	5,340	4,171	20.000	2,262
9/14/2010	15.00	3.45	183.50	10.90	4.67	2.02	507	818	7,375	5.600	164.50	8,930	4,990	20.000	2,670
10/4/2010		3.27	156.54	9.30		1.66			6,695	6.080	178.10	8,210	4,729	20.000	2,487
11/2/2010	15.00	3.51	183.50	11.35	4.90	2.05	535	880	7,560	6.700	137.00	11,400	5,170	20.000	2,880
11/3/2010	14.00	3.20	162.00	9.77	3.91	1.87	578	820	6,685	6.070	155.10	8,650	4,517	20.000	2,472
12/7/2010		3.36	166.86	9.73	4.56	2.07			6,694	5.400	131.10	9,530	4,516	20.000	2,272
1/5/2011		3.24	204.00	11.00	4.00	2.00	665	904	7,840	6.200	133.00	17,500	5,400	20.000	2,640
3/9/2011	12.00	3.33	218.00	13.00	5.00	2.00	691	899	7,540	5.600	101.00	18,100	5,100	20.000	2,360
5/4/2011	30.00	3.53	154.00	9.00	4.00	2.00	509	700	7,000	5.500	90.00	13,100	4,120	20.000	2,270
9/7/2011	17.00	4.41	175.00	10.00	4.00	2.00	568	812	5,630	6.200	174.00	8,160	4,220	20.000	2,440
11/2/2011	17.00	5.66	173.00	10.00	4.00	2.00	564	794	6,620	6.100	129.00	14,100	4,710	20.000	2,365
AVERAGE	45.86	3.80	139.64	8.57	3.60	1.68	451	707	5,614	4.920	130.33	7,848	3,742	15.385	1,997

2.0 SOURCE WATER CONSIDERATIONS

Two Cement Creek treatment scenarios were selected for initial evaluation. The first was to treat the total flow, except peak flows, in upper Cement Creek near Gladstone (CC-18). This approach would treat approximately the same peak flow treated by the previous treatment facility (4.5± cfs). The second scenario would involve the collection and treatment only of the major adit flows, to the extent possible, in upper Cement Creek (i.e. above Gladstone. The four potential adits are:

- American Tunnel
- Gold King Mine
- Mogul Mine
- Red & Bonita Mine

The details related to the collection and routing for each adit water source, cost of collection and conveyance, and other engineering issues that may limit the conveyance of these drainages to a central treatment location were considered. Based on these considerations, the Mogul Mine discharge was deemed impractical primarily due to its location 1.5 miles from the potential Gladstone treatment area and because it would be very difficult to access during the winter.

Photo 1 shows the drainage runoff and general area of the American Tunnel (2011). Photo 2 shows the Gold King Mine area (2012). Photo 3 provides a general view of the Mogul Mine Site (2011). Photo 4 provides an overview of the Red & Bonita Adit (2011).

Photo 1 – American Tunnel Adit

Photo 2 – Gold King Adit

Photo 3 – Mogul Mine Adit

Photo 4 – Red & Bonita Adit

Tables 2 to 7 provide a summary of available USEPA water quality and flow information for these four drainage sources, upper Cement Creek near Gladstone (CC-18) and lower Cement Creek near Silverton (CC-48) from May 2009 through October 2011. The sampling schedule was seasonally limited (i.e., access to sampling locations is limited due to snow and climatic conditions). The analytical results appear to be consistent over time between each sample and the database is large enough to provide a reasonably robust basis for statistical analysis within a very recent timeframe.

Table 2

American Tunnel (CC-19)

Date	Flow (cfs)	Cd (µg/L)	Cu (µg/L)	Zinc (µg/L)	pH (units)	TSS (mg/L)
May 19/09	0.318	2.6	7.9	19,500	4.91	--
June 16/09	0.309	2.5	7.0	17,900	5.17	24
July 14/09	0.231	2.5	6.2	20,000	5.11	26
August 18/09	0.212	2.5	6.3	19,600	5.04	<20
September 22/09	0.221	2.5	6.6	20,500	5.16	<20
November 17/09	0.278	2.3	6.5	21,400	5.14	<20
February 17/10	0.178	2.3	5.9	19,000	5.19	<20
March 17/10	0.204	2.3	8.9	19,700	4.46	<20
April 13/10	0.204	2.4	6.6	20,600	5.38	<20
June 2/10	0.240	2.3	10.0	18,700	5.29	<20
July 13/10	0.240	2.1	5.0	18,300	5.26	<20
September 14/10	0.268	2.1	10.0	17,800	4.47	<20
November 2/10	0.240	2.3	10.0	21,000	5.17	27
March 15/11	0.212	2.0	10.0	20,500	5.18	<20
June 14/11	0.240	2.3	10.0	19,100	4.86	28
July 19/11	0.212	2.2	20.0	19,700	5.04	25
August 16/11	0.221	2.2	20.0	19,000	4.95	60
September 13/11	0.221	2.1	20.0	18,500	5.13	<20
October 18/11	0.240	2.1	20.0	20,800	5.08	28
Average	0.236	2.3	10.0	19,558	5.05	31

Table 3

Gold King Mine (CC-06)

Date	Flow (cfs)	Cd (µg/L)	Cu (µg/L)	Zinc (µg/L)	pH (units)	TSS (mg/L)
May 19/09	0.423	111	10,600	40,300	3.07	20*
June 16/09	0.498	60	5,680	23,800	3.68	29
July 14/09	0.436	61	5,710	24,800	3.19	30
August 18/09	0.358	66	7,150	26,300	3.31	<20
September 22/09	0.151	64	5,630	23,000	3.86	20
November 17/09	0.400*	60*	5,500*	25,000*	3.50*	20*
February 17/10	0.400*	60*	3,500*	35,000*	3.80*	20*
March 17/10	0.500*	38	2,710	15,200	4.96	<20
April 13/10	0.33	41	4,060	14,500	5.13	<20
June 2/10	0.558	136	12,300	44,700	3.15	<20
July 13/10	0.485	62	5,360	23,500	3.03	26
September 14/10	0.449	57.5	5,480	19,500	3.52	23
November 2/10	0.473	53	4,020	20,000	4.13	<20
March 15/11	0.400*	40*	5,500*	25,000*	3.80*	20*
June 14/11	0.328	136	12,400	402	2.55	20
July 19/11	0.298	61	9,930	33,400	2.79	<20
August 16/11	0.313**	70	8,363	27,550	2.87	20
September 13/11	0.332**	57	6,514	24,648	3.10	<20
October 18/11	0.321**	59	5,223	24,353	3.59	<20
Average	0.392	68	6,596	26,882	3.40	21

*Estimated value
**Weighted average of GK and GK West

Table 4

Mogul Mine (CC-02)

Date	Flow (cfs)	Cd (µg/L)	Cu (µg/L)	Zinc (µg/L)	pH (units)	TSS (mg/L)
May 19/09	0.259	41.3	41.3	28,200	3.11	--
June 16/09	0.108	57.2	50.4	28,000	3.63	22
July 14/09	0.178	62.1	45.5	32,900	3.52	26
August 18/09	0.109	60.8	31.4	34,800	3.50	<20
September 22/09	0.109	58.4	30.9	34,200	3.72	25
November 19/09	0.123	50.1	21.6	34,700	3.50	<20
February 17/10	0.154	43.1	16.9	29,400	3.54	<20
March 17/10	0.200*	40.8	17.9	29,200	3.36	<20
April 13/10	0.200*	41.4	19.7	27,800	3.38	<20
June 2/10	0.138	40.3	22.6	24,500	3.58	<20
July 14/10	0.095	54.3	31.6	31,300	3.48	<20
September 14/10	0.109	57.2	23.4	33,600	3.48	24
November 2/10	0.102	54.0	14.7	34,500	3.38	<20
March 15/11	0.200*	40.0*	20.0*	30,000*	3.40*	20*
June 14/11	0.212	36.8	24.6	25,300	3.58	20
July 19/11	0.088	50.1	35.2	30,500	3.48	<20
August 16/11	0.130	60.4	29.9	33,000	3.39	<20
September 13/11	0.095	58.4	29.5	32,600	3.53	<20
October 18/11	0.095	54.1	20.0	33,200	3.42	<20
Average	0.136	50.6	28.0	30,932	3.47	23

*Estimated value

Table 5

Red & Bonita Mine (CC-03D)

Date	Flow (cfs)	Cd (µg/L)	Cu (µg/L)	Zinc (µg/L)	pH (units)	TSS (mg/L)
May 19/09	0.749	33.3	50.6	15,600	5.86	23*
June 16/09	0.699	34.8	4.5	13,600	6.4	33
July 14/09	0.664	34.9	6.2	15,500	6.5	23
August 18/09	0.676	34.6	6.9	15,800	6.22	25
September 22/09	0.749	35.9	4.1	16,400	6.35	28
November 17/09	0.6*	37.7	8.6	17,400	5.95	23
February 17/10	0.5*	37.5	47.1	16,000	5.44	22
March 17/10	0.4*	37.6	14.2	16,500	5.76	22
April 13/10	0.403	37.3	18.0	17,500	5.94	28
June 2/10	0.484	40.4	14.3	15,500	5.94	28
July 13/10	0.517	37.1	10.0	14,500	5.89	23
September 14/10	0.541	35.5	17.8	15,300	6.14	25
November 2/10	0.460	38.0	11.3	16,600	6.46	27
March 15/11	0.5*	33.0	16.7	15,500	6.07	33
June 14/11	0.724	31.8	38.2	14,800	6.17	25
July 19/11	0.676	30.0	20.0	14,500	6.28	32
August 16/11	0.700	29.0	20.0	13,400	6.05	<20
September 13/11	0.74	38.5	47.4	13,500	5.96	51
October 18/11	0.709	52.0	32.3	16,200	5.79	51
Average	0.610	36.26	18.8	15,479	6.06	29

*Estimated value

Table 6

Upper Cement Creek (CC-18)

Date	Flow (cfs)	Cd (µg/L)	Cu (µg/L)	Zinc (µg/L)	pH (units)	TSS (mg/L)
May 19/09	48.8	5.4	185	1,710	3.86	20
June 16/09	12.3	10.4	341	3,410	3.83	20
July 14/09	5.94	16.0	516	5,610	3.73	20
August 18/09	2.29	30.1	1,400	12,300	3.45	20
September 22/09	3.66	27.2	896	10,800	3.72	54
November 17/09	2.67	26.8	853	12,400	3.62	20
February 17/10	1.77	28.2	750	12,300	3.51	20
March 17/10	1.99	27.8	626	12,400	3.48	28
April 13/10	3.76	20.2	563	8,710	3.68	20
June 2/10	29.4	6.8	231	2,000	3.83	20
July 13/10	3.59	16.5	492	5,890	3.59	20
September 14/10	2.31	26.5	932	11,200	3.58	20
November 2/10	2.42	26.9	686	10,400	3.72	20
March 15/11	1.63	24.7	529	11,300	3.61	27
June 14/11	46.2	5.1	163	1,520	3.72	20
July 19/11	14.3	8.0	245	2,920	3.82	20
August 16/11	3.52	20.6	720	8,360	3.24	20
September 13/11	2.68	25.5	794	9,620	3.49	50
October 18/11	3.59	26.6	639	9,330	3.57	24
Average	10.15	20.0	608	8,009	3.63	24

Table 7

Lower Cement Creek (CC-48)

Date	Flow (cfs)	Cd (µg/L)	Cu (µg/L)	Zinc (µg/L)	pH (units)	TSS (mg/L)
May 20/09	22.7	2.1	56.3	640	5.4	--
June 17/09	58	3.3	94.6	1,130	4.29	<20
July 15/09	28	110.0	115.0	1,600	3.95	<20
August 19/09	18	6.4	224.0	2,580	3.51	<20
September 23/09	18	6.6	19.2	2,690	3.65	<20
November 19/09	15.3	5.5	159.0	2,890	3.50	20
February 18/10	14*	54.0	122.0	2,570	3.50	35
March 18/10	13.7	5.3	116.0	2,730	3.48	<20
April 14/10	26.4	4.5	107.0	1,770	3.93	<20
June 3/10	137	2.3	78.0	655	5.34	30
July 13/10	21.0	4.8	126.0	1,720	3.57	20
September 15/10	15.0	5.8	166.0	2,480	3.45	<20
November 4/10	15.0	6.8	141.0	2,600	3.51	<20
March 15/11	14.9	5.0	90.0	2,400	3.54	23
June 15/11	216	2.0	55.6	551	5.24	34
July 20/11	65	3.1	82.8	1,100	4.54	<20
August 17/11	20	5.3	147.0	1,970	3.45	<20
September 14/11	17.0	5.7	156.0	2,160	3.51	<20
October 19/11	18.0	7.1	136.0	2,510	3.24	<20
Average	40.6	13.5	118.6	2,006	3.84	27

*Estimated value

Based upon USEPA data from May 2009 through October 2011, the average daily metal loads from the four individual adits and upper and lower Cement Creek based on average flows and metal load were calculated and are presented in Table 8. This calculation is not based on daily flow and load, but it provides a reasonable comparative indication of potential sources and quantities of the key constituents of concern. It also provides a method to evaluate the impact of each constituent source on its relative contribution to upper and lower Cement Creek.

Table 8

Analysis of Sampling Results May 2009 - October 2011
(lb/Day of average flow)

Sample Site	Flow	Cd	Cu	Zinc	TSS
Average Value	**MGD**	**lb/Day**	**lb/Day**	**lb/Day**	**lb/Day**
Red & Bonita	0.385	0.121	0.060	49.91	94.25
Gold King Mine	0.269	0.405	14.140	53.31	64.40
Mogul Mine	0.088	0.037	0.020	22.72	16.69
American Tunnel	0.152	0.006	0.017	24.84	39.59
Adit Sources Avg.	**0.894**	**0.570**	**14.240**	**150.78**	**214.93**
Cement Ck. Lower (CC-48)	26.17	1.69	25.89	437.87	5,893.85
Cement Ck. Upper (CC-18)	6.58	1.09	33.38	439.44	1,377.40
Adit % Sources to Lower CC	3.43	33.7	55.0	34.4	3.6
Adit % Sources To Upper CC	13.6	55.3	42.6	34.3	15.6

CC – Cement Creek
MGD – million gallons day

Based upon an evaluation of the data presented in Tables 2 to 8, a number of site specific characteristics were observed. Water quality in Cement Creek and the four specific source "adits", have the following general attributes:

American Tunnel drainage has elevated zinc but very low (lowest of the four) copper and cadmium concentrations and load.

Gold King Mine drainage is high in cadmium and zinc, but very noticeably is the largest source of copper (by orders of magnitude), in comparison to the three other sources. The Gold King Mine obviously is the main source of copper in Cement Creek.

Mogul Mine drainage has very high zinc concentrations however, because of its low flow, the zinc load to Cement Creek is comparable to the American Tunnel.

Red & Bonita Mine drainage, while having the lowest zinc concentration of the four adits, because of its higher flow, it is a significant source of the zinc load in Cement Creek.

Cement Creek Sites (upper and lower) – The in-stream pH, copper, cadmium, and zinc concentrations are elevated to a level that would be in excess of the freshwater chronic standard for cold water fish. However, since Cement Creek is historically not a sustaining fishery, this criterion is not relevant from a practical point of view. The pH is depressed significantly throughout the year. As shown in Table 8, for the three constituents of particular concern in this analysis (zinc, cadmium and copper) a significant portion of the metal mass loading to both upper and lower Cement Creek emanates from the Gold King drainage. The zinc contribution from drainage originating at the Gold King Mine adit (over the period summarized in Table 8) accounts for 12 percent (%) of the loading in both the upper and lower Cement Creek sites. For the copper loadings, Gold King drainage accounts for essentially all (99.4 %) of the copper discharged from the four adits combined; and 49 percent of the total load in lower Cement Creek (CC-48) and 38 percent of the load at upper Cement Creek (CC-18). There is an indication that the copper loading is being reduced between upper Cement Creek and lower Cement Creek by loss (precipitation and settling).

3.0 BENCH SCALE TREATABILITY TESTING – CEMENT CREEK

A sample for bench scale testing of Cement Creek water was collected at the CC-18 location near Gladstone below the confluence of the American Tunnel in February of 2012. The sample was characterized and compared to available recent Cement Creek water quality information in Table 9. Table 9 also provides the high and low concentrations of several key water quality parameters from samples collected from 2009 through 2011 for comparison. The comparison indicates that the treatability sample is generally representative of current and recent water quality conditions that exist in upper Cement Creek. The treatability sample metal concentrations generally fall within the high end of the historic range except for lead and zinc which were higher than the historic range

Table 9

Comparison of Treatability Sample to Recent Monitoring Data from Upper Cement Creek (CC-18) for Selected Constituents

Constituent	Units	High***	Low***	February 2012 Treatability Sample (at CC-18)
pH	S.U.	3.86	3.24	3.07
Aluminum (Al)	mg/L	9.64	1.61	8.99
Iron (Fe)	mg/L	39.8	4.70	6.18
Manganese (Mn)	mg/L	199.9	1.72	25.4
Cadmium (Cd)	µg/L	30.1	5.1	29.8
Copper (Cu)	µg/L	1,400	163	417
Lead (Pb)	µg/L	80.4	9.6	51.1
Zinc (Zn)	µg/L	12,400	1,520	13,300

***2009-2011 data

The treatability testing evaluated four conventional methods to remove dissolved solids as chemical precipitated solids. These four chemical/physical treatment methods represent typical approaches that would be considered for removal of metals from mine drainage. These included:

- Lime - Hydroxide precipitation using lime alum (experiment series 1)
- Ferric Chloride and Lime - Enhanced coagulation following hydroxide precipitation using ferric chloride (experiment series 2)
- Sulfide and Lime - Metal sulfide precipitation (experiment series 3)
- Oxidation Co-precipitation and Lime - Metal co-precipitation using ferric and manganese oxidation and pH adjustment (experiment series 4)

Appendix A provides a separate report detailing the treatability methods, procedure and results.

Table 10 provides a summary of the results of the four selected, conventional treatability protocols (lime, ferric chloride and lime, sulfide and lime, and oxidation co-precipitation and lime) as described in more detail in Appendix A.

As can be seen from the results on Table 10, high lime treatment (pH 9 – 10) was the most effective for removal of constituents of significant interest (Zn, Cu, Cd), as well as most other divalent and trivalent metals. The only apparent exception was aluminum which is known to be less soluble at lower pH levels (7 to 8). The other three experimental protocols did not produce comparable results and did not prove to be of any advantage for providing improved removal effectiveness.

Table 11 provides a summary of the "best apparent" treatment process using lime at pH 10 (best) and pH 9 (second best overall). The pH 10 option would generate approximately 26 percent more solids (dry solids basis) for disposal so the decision on what the final target operating pH should be becomes more critical. For example, at the current proposed treatment flow for upper Cement Creek (1,000 gpm), the lime treatment option at pH 10 would generate approximately 2,120 lbs/day of dry solids. At pH 9, this is reduced to 1,570 lbs/day of dry solids. On a dewatered wet solids basis (filtered), the mass increases by approximately seven times. Since residual/solids management will be a critical element of any treatment alternative, the selection of the optimal system criteria is important.

Since lime treatment appears to provide the best overall treatment results, the remainder of this evaluation will be focused on lime treatment alternatives.

Table 10

Analytical Results of Bench-Scale Experiments

Analyte	Source Water	Experiment 1-1 Lime pH 7	Experiment 1-2: Lime pH 8	Experiment 1-3: Lime pH 9	Experiment 1-4: Lime pH 10	Experiment 2-1: 15 mg/L Fe	Experiment 2-2: 30 mg/L Fe	Experiment 2-3: 60 mg/L Fe	Experiment 2-4: 120 mg/L Fe	Experiment 3-1: Sulfide Pre-dose	Experiment 3-2: Sulfide Post-dose	Experiment 4-1: Hypochlorite	Experiment 4-2: Peroxide
TDS, mg/L	1,540	1,540	1,540	1,530	1,550	1,600	1,630	1,730	1,890	1,590	1,570	1,650	1,530
SO_4, mg/L	1,050	1,020	1,030	1,020	1,020	1,030	1,030	1,020	987	1,010	1,040	1,020	1,030
Cl, mg/L	0.25	1.01	0.74	0.72	0.59	27.7	62.4	112	236	9.98	0.77	79.7	2.14
F, mg/L	4.27	3.81	4.07	4.10	3.91	3.86	4.83	3.94	3.56	3.95	4.06	3.50	3.94
Na, mg/L	7.10	6.91	7.06	6.99	6.96	7.18	7.24	6.94	6.92	49.3	49.1	78.9	7.20
K, mg/L	1.43	1.73	1.79	1.56	1.58	2.16	1.59	1.55	1.55	2.06	1.82	2.26	3.61
Mg, mg/L	22.0	21.4	21.6	21.4	19.3	21.7	21.0	20.9	21.1	21.7	21.3	21.2	20.8
Ca, mg/L	336	378	390	399	417	416	446	462	537	362	369	400	398
Al, mg/L	8.99	ND	ND	0.086	0.538	ND	0.098	0.121	ND	0.095	ND	ND	0.095
SiO_2, mg/L	38.8	25.0	20.2	14.8	6.96	16.3	9.86	5.66	3.21	24.4	17.1	21.4	15.3
Fe, mg/L	6.18	ND	ND	ND	ND	ND	ND	ND	ND	0.176	ND	ND	ND
Mn, mg/L	25.4	23.3	25.3	16.4	0.258	20.2	12.6	10.4	6.40	23.4	15.4	0.0405	4.86
As, µg/L	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND
Sb, µg/L	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND
Se, µg/L	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND
Sr, mg/L	3.59	3.53	3.54	3.54	3.54	3.56	3.61	3.47	3.51	3.50	3.44	3.46	3.50
Ba, µg/L	26.0	30.9	24.4	17.0	15.8	25.5	19.2	13.3	11.0	14.1	20.9	5.6	13.6
Be, µg/L	3.79	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND
Cd, µg/L	29.8	23.7	13.3	2.1	ND	9.2	2.4	1.5	0.5	ND	ND	0.6	1.5
Co, µg/L	76.9	70.4	59.6	23.8	1.2	51.4	2.17	1.24	7.7	11.5	16.3	1.3	20.1
Cu, µg/L	417.0	5.3	2.2	1.3	1.0	1.4	1.3	1.1	ND	1.5	1.8	2.4	1.2
Pb, µg/L	51.1	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND
Ni, µg/L	47.8	43.6	37.9	24.3	9.8	36.9	24.4	20.3	18.7	25.2	35.8	13.4	24.6
Zn, µg/L	13,300	6,170	925	38.6	6.1	737	171	80.1	47.6	13.4	41.3	171	163

ND = not detected

Table 11

Best Apparent Treatment Results
Lime Precipitation at pH 9 and pH 10
(Based on Source Water Quality)

Analyte	Source Water	Treated @ pH 10	% Removal @ pH 10	Treated @ pH 9	% Removal @ pH 9
TDS, mg/L	1,540	1,550	-1	1,530	2
SO_4, mg/L	1,050	1,020	3	1,020	3
Cl, mg/L	0.25	0.59	-200	0.72*	-30
F, mg/L	4.27	3.91	8	4.10	4
Na, mg/L	7.10	6.96	3	6.99	2
K, mg/L	1.43	1.58	2	1.56	9
Mg, mg/L	22.0	19.3	12	21.4	3
Ca, mg/L	336	417	-24	399	-1
Al, mg/L	8.99	0.538	94	0.086	99
SiO_2, mg/L	38.8	6.96	82	14.8	62
Fe, mg/L	6.18	ND	100	ND	100
Mn, mg/L	25.4	0.258	99	16.4	35
As, µg/L	ND	ND	ND	ND	ND
Sb, µg/L	ND	ND	ND	ND	ND
Se, µg/L	ND	ND	ND	ND	ND
Sr, mg/L	3.59	3.54	2	3.54	2
Ba, µg/L	26.0	15.8	39	17.9	31
Be, µg/L	3.79	ND	100	ND	100
Cd, µg/L	29.8	ND	100	2.1	94
Co, µg/L	769	1.2	99	23.8	97
Cu, µg/L	417	1.0	99	1.3	98
Pb, µg/L	81.1	ND	100	ND	100
Ni, µg/L	47.8	9.8	80	24.3	49
Zn, µg/L	13,300	6.1	99.9	38.6	99

Increase from source reported as –
*Dilution error due to low chlorides

4.0 FEASIBLE AVAILABLE TREATMENT ALTERNATIVES

Evaluation of the constituents of concern in Cement Creek was limited to the parameters discussed earlier: zinc, copper, cadmium, pH, and total suspended solids (TSS). Discounting the peak flow (maximum measured month discharge) over the May – July period, the seasonal average flow at CC-18 (discharge of upper Cement Creek) is approximately 3.1 cfs (1,389 gpm). The average annual flow from the three adits (seasonal flows are relatively constant) that could be collected and conveyed (piped) for treatment (excepting the Mogul Mine) is approximately 0.814 cfs (365 gpm). The maximum month (maximum combined measured) flow for the three adits (June 2009) is approximately 1.5 cfs (676 gpm).

A treatment flow of at least 1,000 gpm would provide for the combined average maximum (discounting a peak event) flow from the three adits as well as a significant (but varying) portion of the upper Cement Creek flow that could be diverted for treatment. Providing a system to treat the potential historic measured peak flow (49± cfs) of upper Cement Creek does not appear to be warranted due to the brief duration of those events and the very significant dilution associated with the peak runoff event. As presented in Logsdon's work (Mass Loading Analysis of the upper Animas River at Water Quality Station A-72, 2012), the percentage of loading at A-72 attributable to the Cement Creek drainage during peak flow events is dramatically lower than during low and median flow conditions,

The flow source options considered for treatment were segregated into two separate components for study: 1) the in-stream flow (total or partial) of upper Cement Creek diverted below the American Tunnel drainage discharge similar to the previous operation of the SGC water treatment facility for upper Cement Creek; and 2) the combined flow of the Red & Bonita adit, Gold King Mine adit, and American Tunnel drainage.

The following treatment process alternatives are both technically feasible and reasonable for improving water quality in the Cement Creek drainage by treating either the three identified adit/tunnel drainage sources or the partial (seasonally) instream flow of upper Cement Creek.

Process Alternative	Unit Treatment Processes Considered
1.	pH adjustment using lime in a mechanical mixing/clarifier unit (solids contact clarification) in order to precipitate and remove metal hydroxide solids (settling) from the three adit drainage sources (1,000 gpm design capacity)
2.	Pond settling following pH adjustment with lime and settling aides for the three adit drainage sources (1,000 gpm design capacity) in lined basins
3.	pH adjustment using lime in a mechanical mixing/clarifier unit (solids contact clarification) in order to precipitate and remove metal hydroxide solids (settling) for up to 2,000 gpm of upper Cement Creek flow
4.	Pond settling following pH adjustment with lime in lined settling ponds for up to 2,000 gpm of upper Cement Creek
5.	Media filtration (following the lime chemical treatment process in Alternative 1) to improve solids removal and handling for the three adit drainage sources

4.1 Process Evaluation

As discussed earlier, the bench scale evaluation and empirical testing of the upper Cement Creek water demonstrated that lime treatment at or around pH 10 was very effective (90 – 99 %, ion dependent) for the removal of the constituents of concern. Precipitated solids removal would require settling and/or filtration. The high pH final effluent could be adjusted using acid to an environmentally acceptable level of 6.5 to 7.5; however, given the very acidic nature of upper Cement Creek, direct discharge of high pH water may be advantageous and probably would be of little environmental consequence in the stream area below Gladstone. The reported change in pH at CC-48 during the operation of the earlier SGC water treatment facility, with an effluent discharge of approximately pH 9+, was less than one pH unit. This is due to the natural low pH (high acidity) in Cement Creek and the relatively low buffer capacity of the treated water.

The precipitated metal solids (hydroxides) will require removal prior to discharge of the chemically treated effluent. The pH of Cement Creek is so low that hydroxide solids would be expected to partially or fully re-solubilize if discharged directly into the lower Cement Creek (below Gladstone). Effective solids capture and isolation is key to successful total metal removal.

Options considered for solids removal and containment include two types of settling: 1) a high efficiency mechanical treatment process including solids recirculation (solids contact clarification) and controlled solids management; and 2) pond settling following lime addition, similar to what was used at the earlier treatment facility. Settling often can be enhanced by the addition of settling aids (polymers that can destabilize charged particles and encourage flocculation and more rapid settling) as was the practice at the earlier Cement Creek treatment plant. Solids in mechanical treatment systems are removed continuously and must be stored for further handling, dewatering and disposal. Pond settled solids will need to be removed periodically by decanting the pond and pumping or vacuuming the settled wet solids. A mechanical treatment plant with constant solids handling, storage and removal will be more effective, easier to operate and require less land area than a system using settling ponds. Both of these alternatives are considered in this evaluation.

Another alternative for solids removal following chemical precipitation is direct media filtration. The combined high average flow (spring runoff) for the three adits is relatively low (design 1,000 gpm) and direct filtration may provide a reasonable solids separation alternative. Filtered solids that accumulate on the media would be collected by backwashing the filter units when they are loaded. The backwash flow would be collected in a pond or tank and the solids would be allowed to separate. Clarified filter backwash water would be discharged. Solids would need to be removed periodically for disposal. Treating the entire flow of upper Cement Creek (CC-18) using this approach would not be economical due to the higher seasonal flow (2,000 gpm average) that was used for this evaluation.

The use of other solids removal methods (microfiltration, centrifuges, etc.) was not considered to be necessary or desirable for this application given the bench scale testing results.

4.2 Treatment Alternatives and Combined Treatment Trains

Of the unit process methodologies for upper Cement Creek drainage treatment systems that were considered, the following were consolidated to provide complete treatment trains that would best improve downstream water quality and provide effective operation.

<u>Alternative 1 - Three Adits with Mechanical Treatment</u>

Collection of the flow from the American Tunnel, Gold King and Red & Bonita drainages plus some flow from Cement Creek into a single influent source that would be treated in a mechanical water treatment plant. For planning purposes, the system was sized for a flow of 1,000 gpm to represent a maximum average high monthly flow from the drainage sites and some Cement Creek drainage treatment during lower flow periods.

The treatment process would include pH adjustment with lime in a rapid mix unit and settling of the precipitated solids in a mechanical clarifier using settling aides to improve removal. Part of the settled solids would be recirculated and added back to the rapid mix section along with make-up lime slurry (slaked lime) where a polymer settling aid would be added. The excess solids would be pump discharged to a solids settling/holding pond or tank and the clarified solution would be directed back to Cement Creek.

Solids would be allowed to consolidate by gravity settling in a pond or tank and would need to be disposed of periodically. Disposal as a wet solid would be possible if a disposal site suitable for un-dewatered lime solids is available, or they could be dewatered further to 35 - 45 percent solids for disposal at an acceptable land fill or other disposal site. For this evaluation, it was assumed that solids would be dewatered using a belt or filter press to 40± percent solids and disposal would occur at a landfill within 100 miles of Silverton.

Alternative 2 - Three Adits with Settling Ponds

Alternative 2 would be similar to Alternative 1 but the treatment provided would be less mechanical. The collected flow from the three target drainages and some flow from Cement Creek would be directed to a rapid mix structure where lime would be added to achieve the best target pH (10±). The mixed pH adjusted flow would be directed to a series of four lined settling ponds (two trains of two ponds in series). A settling aid would be mixed with the flocculated flow prior to introduction in the settling ponds. The first pond (primary) in each train would allow for primary settling and solids removal. The second pond (secondary) would allow for final polishing by settling of flow prior to discharge. When the active primary pond requires solids removal cleaning, the flow is switched and the secondary pond becomes the lead primary pond. The initial active primary pond will then have the settled solids removed and be placed back in service as the secondary pond. The primary and secondary settling ponds would be rotated between cleaning cycles. Each pond would be provided with a discharge to Cement Creek.

Settled solids would be removed from the ponds by pumping. Disposal could be at an approved land fill, old mine workings or other locations depending on the solids content of the sludge. For this evaluation, it was assumed that solids disposal would occur at a site within 50 miles of Silverton.

Alternative 3 - Cement Creek Up to 2,000 gpm with Mechanical Treatment

This alternative is identical to Alternative 1 except that the system would be sized to provide for a mechanically treated flow of 2,000 gpm. This approach would allow for a significant portion of the Cement Creek flow to be included during most periods of the year along with the adit flow that reports to upper Cement Creek.

Alternative 4 - Cement Creek Up to 2,000 gpm with Settling Ponds

Alternative 4 would be similar to Alternative 2; however, the treatment system would mirror the previous SGC water treatment plant in that it would be designed to process up to 2,000 gpm of flow from upper Cement Creek. This would require some peak flow to bypass treatment during the peak spring runoff period. During this period, natural dilution (runoff) is significant and the upper Cement Creek water quality is not impacted to the degree that it is during low and median flows. It was estimated that the 2,000 gpm capacity would treat the entire flow of upper Cement Creek approximately 80 percent of the time (based on monthly measurement). This alternative would require a diversion weir structure to be installed in upper Cement Creek to collect and direct the creek flow to the treatment works.

The lime treated flow would have a settling aid addition and be directed to a two-stage settling pond arrangement similar to what was described for Alternative 2. The size required for the ponds (and number of passes) would be designed as a function of the flow to allow for proper settling and solids storage. As in Alternative 2, the primary and secondary ponds in each of the series would be alternated to facilitate periodic solid removal. Effluent would discharge to Cement Creek and solids would be disposed of as described previously.

Alternative 5 - Three Adits with Direct Filtration

For Alternative 5, the flow collected from the three target adits would be chemically treated using lime with rapid mixing and flocculation. This system was sized for a flow of 1,000 gpm which is more than adequate to handle the maximum average high monthly flow from the drainage sites. The resulting solids would be removed through direct pressure media filtration. Filtered solids that accumulate on the media would be collected by backwashing the filter units when they are loaded. The backwash flow would be collected in a pond or tank and the solids would be allowed to separate. Clarified filter backwash water would be discharged. Solids would need to be removed periodically for disposal. Alternatively, the solids could be clarifier settled and the clarifier effluent filtered to maintain longer filter runs. In both cases, it was assumed that the solids would be hauled to a suitable disposal facility within 100 miles of Silverton.

5.0 ALTERNATIVE SCREENING AND EVALUATION

The criteria used for the identification and comparison of treatment alternatives were:

1. Ability to remove the metals of concern (treatability).
2. Process reliability (reliability)
3. Commercially implementable technology (practicality)
4. Reasonable operability and maintenance requirements under site conditions (operability)
5. Ability to handle variable flow conditions (flexibility)
6. Waste disposal management requirement (residual disposal)
7. Infrastructure requirements (infrastructure) for successful operation
    - Power
    - Access
    - Land/land ownership
    - Resource use
8. Environmental compatibility (environmental)
9. Process CAPEX and OPEX requirements (cost)

Table 12 provides a subjective assessment and rating of the five alternatives based upon eight of the evaluation criteria. Cost (Capital and O&M) was considered separately in Section 6 and Section 7. A numerical rating of 1 - 5 was used to rank the alternatives using the eight non-financial criteria. Each of the evaluation criteria were assumed to have equal weighting. Alternatives 1 and 3 would appear to provide the best systems for meeting the criteria proposed.

Table 12

Non-Financial Screening of Alternatives

Alternatives	Screening Criteria: Treatability	Reliability	Practicality	Operability	Flexibility	Removal/Disposal	Infrastructure	Environmental	Total Score
Alternative 1 Adit collection and partial Cement Creek flow treatment with mechanical solids settling and "dry" sludge disposal (1,000 gpm capacity).	5	4	5	4	5	5	4	5	37
Alternative 2 Adit collection and partial Cement Creek flow treatment with pond settling of solids and "wet" sludge disposal (1,000 gpm capacity).	5	3	4	3	5	4	3	3	30
Alternative 3 Cement Creek flow treatment, up to 2,000 gpm, with mechanical solids settling and "dry" sludge disposal.	4	4	5	4	5	5	4	5	36
Alternative 4 Cement Creek flow treatment, up to 2,000 gpm, with pond settling of solids and "wet" sludge disposal.	4	3	4	3	4	4	3	3	28
Alternative 5 Adit collection and treatment with direct filtration of solids and "dry" sludge disposal (1,000 gpm capacity)	3	3	4	3	4	4	4	4	29

Screening Criteria Rating

Best Meets Results........................5
Meets Results................................4
Partially Meets results...................3
Does Not Meet Results..................2
Negative Impacts...........................1

6.0 CAPITAL COST ASSESSMENT

The capital cost opinion (CAPEX) for the alternatives considered to be practical and reasonable are presented in Tables 13 through 17. These should be considered as preliminary capital cost estimates presented for comparative planning purposes. While the information is intended to provide a reasonably accurate comparative opinion of cost between the alternatives for planning purposes, the absolute accuracy is typical of scoping level work. No actual site specific information for any of the three sites was undertaken as part of this study. The flow collection, pipeline and conveyance facilities for the adit flows from Red & Bonita, Gold King and the American Tunnel is based on available mapping using gravity flow C900 PVC pipe or better pipe that would be designed to be free draining, not subject to inlet freezing and would maintain sufficient pipe velocity. Five feet of pipe burial (actual conditions unavailable) was assumed in order to operate through the winter. Collection of the adit discharge was assumed to use a buried concrete spring box protected from freezing. The practicality of the concept proposed requires additional study. The 1,000 gpm flow for Alternative 1 allows treatment of the maximum sustained average flow for the combined adit sources (three sources considered) plus additional capacity to treat a portion of upper Cement Creek flow.

Pond treatment of upper Cement Creek was limited to a 2,000 gpm system. The treatment alternatives for which capital cost information were developed follows:

Alternative	Description
1	Collection and mechanical chemical treatment of the flow from the three target adits plus additional flow from upper Cement Creek sized at 1,000 gpm.
2	Collection and chemical treatment and pond settling of the flow from the three target adit plus additional flow from upper Cement Creek sized at 1,000 gpm.
3	Chemical and mechanical treatment of upper Cement Creek flow sized at 2,000 gpm.

Alternative	Description
4	Chemical treatment and pond settling and solids storage and wet solids disposal locally of the partial flow of upper Cement Creek flow sized at 2,000 gpm.
5	Collection and mechanical chemical treatment and settling of solids from the flow from the three target adits followed by direct filtration sized at 1,000 gpm.

The capital cost estimates are very dependent on the design flow assumed. Those flows were based on the information available and need to be reviewed prior to initiating design work. The capital costs for the mechanical treatment alternatives include solids dewatering equipment necessary to increase the solids density beyond what can be achieved through gravity settling. Pond treatment alternatives assume local disposal of wet solids and do not include the same solids dewatering equipment.

Table 13

Conceptual Capital Cost Opinion - Alternative 1
Collected Flow from American Tunnel, Gold King and Red & Bonita and Some Partial Flow from Cement Creek
Process: Chemical Treatment using a Mechanical System
(1,000 gpm design flow)

Component	Units	Unit Cost($)	Cost $	Comments
1. Adit Bulkhead & Collection	3	$250,000	$750,000	Concrete
2. Collection Piping	6,300 ft	$45	$284,000	12" Ø
3. Civil/ Site Work	100,000 ft^2	$1.25	$125,000	
4. Cement Creek Diversion & Piping (incl.)	60 cy	$5,000	$300,000	Cement Weir
5. Equalization Tank & Pumping	LS	$30,000	$30,000	Lined Steel
6. Solid Contact Clarifier (complete) with solids handling	1 Unit	$1,110,000	$1,110,000	DensaDeg™ or Similar
7. Dry Chemical Storage Feed	1	$110,000	$110,000	Silo/pneumatic
8. Lime Slaking & Feed	1	$200,000	$200,000	Max 6,000 lb/day
9. Solids Holding Tank	1	30,000	$30,000	Poly
10. Yard Piping	LS	$75,000	$75,000	
11. Process Building (complete)	2,200 ft^2	$110	$242,000	Insulated Pre-engineered
12. Miscellaneous. Mechanical	LS	$100,000	$100,000	
13. Civil / Site Work	150,000 ft^2	$1.25	$188,000	
14. Instrumentation & Control	LS	$75,000	$75,000	
15. Electrical	LS	$700,000	$700,000	
16. Miscellaneous	LS	$100,000	$100,000	
17. Solids Handling and Belt Press Dewatering (complete)	1	$80,000	$80,000	
Subtotal			***$4,499,000***	
Contractor Profit, Overhead, Mobilization, Insurance, etc. (25%)			$1,125,000	
Design Engineering, Admin, Permitting, Legal (20%)			$900,000	
TOTAL COST			**$6,524,000**	

Notes Common for All Alternatives:
1. No contingency included
2. No land or ROW costs included
3. No primary electrical cost included
4, All costs installed

Table 14

Conceptual Capital Cost Opinion - Alternative 2
Collected Flow from American Tunnel, Gold King and Red & Bonita and Some Partial Flow from Cement Creek
Process: Chemical Treatment with Lime, 4 Settling Ponds, and Solids Storage
(1,000 gpm design flow)

Component	Units	Unit Cost($)	Cost $	Comments
1. Adit Bulkhead & Collection	3	$250,000	$750,000	Concrete
2. Collection Piping	6,300 ft	$45	$284,000	12" Ø
3. Civil/ Site Work	100,000 ft^2	$1.25	$125,000	
4. Cement Creek Diversion & Piping (incl.)	60 cy	$5,000	$300,000	Cement Weir
5. Influent Equalization and Chemical Mix Tank	1	$75,000	$75,000	30 Mins Poly Retention
6. Lined Pond	30,000 ft^2	$5.25	$158,000	4 ponds, 45 mil, single liner, 8 hr retention
7. Dry Chemical Storage Feed	1	$160,000	$160,000	Silo/pneumatic
8. Lime Slaking & Feed	1	$260,000	$260,000	Max 10,000 lb/day
9. Sludge Pump	1	$45,000	$45,000	
10. Process Building (complete)	1,500 ft^2	$110	$165,000	
11. Miscellaneous. Mechanical	LS	$100,000	$100,000	Insulated Pre-engineered
12. Yard Piping	LS	$100,000	$100,000	
13. Civil / Site Work	150,000 ft^2	$1.25	$188,000	
14. Electrical	LS	$350,000	$350,000	
15. Instrumentation & Control	LS	$30,000	$50,000	
16. New Solids Disposal Area	1	$1,000,000	$1,000,000	
Subtotal			***$4,110,000***	
Contractor Profit, Overhead, Mobilization, Insurance, etc. (25%)			$1,028,000	
Design Engineering, Admin, Permitting, Legal (20%)			$ 822,000	
TOTAL COST			**$5,960,000**	

*Assumes wet solids disposal

Table 15

Conceptual Capital Cost Opinion - Alternative 3
Upper Cement Creek Partial Annual Flow
Process: Chemical Treatment using a Mechanical System
(2,000 gpm design flow)

Component	Units	Unit Cost($)	Cost $	Comments
1. Civil/Site work	100,000 ft^2	$1.25	$125,000	
2. Cement Creek Diversion & Piping (incl)	60 cy	$5,000	$300,000	Cement Weir
3. Equalization Tank & Pumping	LS	$50,000	$50,000	Lined Steel
4. Solid Contact Clarifier (complete) with solids handling	1	$1,810,000	$1,810,000	DensaDeg™ or Similar
5. Dry Chemical Storage Feed	1	$180,000	$180,000	Silo/pneumatic
6. Lime Slaking & Feed	1	$200,000	$200,000	Max 6,000 lb/day
7. Solids Holding Tank	1	50,000	$50,000	Poly
8. Yard Piping	LS	$75,000	$75,000	
9. Process Building (complete)	2,500 ft^2	$110	$275,000	Insulated Pre-engineered
10. Miscellaneous. Mechanical	LS	$130,000	$130,000	
11. Civil / Site Work	150,000 ft^2	$1.25	$188,000	
12. Instrumentation & Control	LS	$75,000	$75,000	
13. Electrical	LS	$750,000	$750,000	
14. Miscellaneous	LS	$100,000	$100,000	
15. Solids Handling and Belt Press Dewatering (complete)	1	$110,000	$110,000	
Subtotal			***$4,418,000***	
Contractor Profit, Overhead, Mobilization, Insurance, etc. (25%)			$1,105,000	
Design Engineering, Admin, Permitting, Legal (20%)			$884,000	
TOTAL COST			**$6,407,000**	

Table 16

Conceptual Capital Cost Opinion - Alternative 4
Upper Cement Creek Partial Annual Flow
Process: Chemical Treatment with Lime, 4 Settling Ponds, and Solids Storage
(2,000 gpm design flow)

Component	Units	Unit Cost($)	Cost $	Comments
1. Civil Site Work	6,300 ft^2	$45	$284,000	12" Ø
2. Cement Creek Diversion & Piping (incl)	60 cy	$5,000	$300,000	Cement Weir
3. Influent Equalization and Chemical Mix Tank	1	$75,000	$75,000	30 Mins Poly Retention
4. Lined Pond	45,000 ft^2	$5.25	$236,000	4 ponds, 45 mil, single liner, 8 hr retention
5. Dry Chemical Storage Feed	1	$160,000	$160,000	Silo/pneumatic
6. Lime Slaking & Feed	1	$260,000	$260,000	Max 10,000 lb/day
7. Sludge Pump	1	$45,000	$45,000	
8. Process Building (complete)	1,500 ft^2	$110	$165,000	
9. Miscellaneous. Mechanical	LS	$100,000	$100,000	Insulated Pre-engineered
10. Yard Piping	LS	$150,000	$150,000	
11. Civil / Site Work	150,000 ft^2	$1.25	$188,000	
12. Electrical	LS	$350,000	$350,000	
13. Instrumentation & Control	LS	$30,000	$30,000	
14. New Solids Disposal Area	1	$1,500,000	$1,500,000	
Subtotal			***$3,843,000***	
Contractor Profit, Overhead, Mobilization, Insurance, etc. (25%)			$961,000	
Design Engineering, Admin, Permitting, Legal (20%)			$769,000	
TOTAL COST			**$5,573,000**	

*Assumes wet solids disposal

Table 17

Conceptual Capital Cost Opinion - Alternative 5
Collected Flow from Gold King, Red & Bonita and American Tunnel
Process: Chemical Treatment followed by Direct Filtration
(1,000 gpm design flow)

Component	Units	Unit Cost($)	Cost $	Comments
1. Adit Bulkhead & Collection	3	$250,000	$750,000	Concrete
2. Collection Piping	6,300 ft	$45	$284,000	
3. Equalization Tank & Pumping	1	$75,000	$75,000	30 mins retention, Poly Tank w/mixer
4. Dry Chemical Storage Feed	1	$160,000	$160,000	
5. Lime Slaking & Feed	1	$260,000	$260,000	
6. Pumps to Filters (duplex)	1	$60,000	$60,000	Duplex
7. Pressure Filters	2	$45,000	$90,000	FRP Pressure
8. Backwash Pumping	1	$60,000	$60,000	Duplex
9. Backwash Recovery Pond & Solids Storage	1,200 ft^2	$5.50	$7,000	2 ponds with pump structure
10. Solids Pumping	1	$45,000	$45,000	
11. Process Building	2,000	110	$220,000	Insulated, Pre-engineered
12. Miscellaneous Mechanical	LS	$100,000	$100,000	
13. Yard Piping	LS	$100,000	$100,000	
14. Civil / Site Work	150,000 ft^2	1.25	$188,000	
15. Electrical	LS	$600,000	$600,000	
16. Instrumentation & Control	LS	$50,000	$50,000	
17. Solids Handling and Belt press Dewatering (complete)	2	$40,000	$80,000	
Subtotal			***$3,129,000***	
Contractor Profit, Overhead, Mobilization, Insurance, etc. (25%)			$782,000	
Design Engineering, Admin, Permitting, Legal (20%)			$626,000	
TOTAL COST			**$4,537,000**	

Note: Alternative 5 assumed direct filtration without settling which will require additional study to determine treatability operational risk.

Ranking of the concept capital cost are as follows:

Alternative 1.....................$6,524,000 (Mechanical – 1,000 gpm)
Alternative 2.....................$5,960,000 (Pond – 1,000 gpm)
Alternative 3.....................$6,407,000 (Mechanical – 2,000 gpm)
Alternative 4.....................$5,573,000 (Pond – 2,000 gpm)
Alternative 5.....................$4,537,000 (Filter – 1,000 gpm)

7.0 OPERATIONS AND MAINTENANCE

The operational and maintenance (O&M) cost opinion for the alternatives include the following components:

- Chemical (lime and polymer) use
- Electrical power
- Labor and training
- Sludge/solid disposal
- Replacement cost for material and equipment (parts and supplies)
- Laboratory and consultant cost

These O&M costs are intended to be estimates. For this evaluation, the cost of lime was assumed at $190 ton delivered. On line electrical power (utility) was assumed to be in the $0.15 kWh range. Labor cost (each full-time employee) was estimated at $45,000 plus 32 percent for benefits ($59,000) for the operator(s) of the treatment facility. It was assumed that six full-time employees (two per shift) would be required for year-round operation based on discussion with the operator of the previous WTP.

Dewatered lime sludge disposal at a controlled, but nonhazardous disposal site, was assumed at $10 per dewatered cubic foot based on similar projects. Contract hauling costs to a solids disposal site within a 200 mile round-trip were estimated at $1,000 per trip for dewatered solids. This would require that the solids be dewatered to 30 – 40 percent solids to satisfy the requirements of most commercial disposal sites. These operating cost assumptions were applied to Alternatives 1, 3, and 5. As noted previously, the capital cost estimates for these alternatives include the additional dewatering equipment necessary to achieve these requirements.

Pond settled solids would be removed from the ponds and hauled as wet solids (10 %+/- solids) and would be truck hauled for disposal at a new, controlled disposal site assumed to be located within 50 miles of the WTP facilities. Removal and hauling cost were estimated at $0.09 per gallon based on similar operating facilities. These operating cost assumptions were applied to Alternatives 2 and 4. These alternatives include a capital expenditure for developing the new disposal site in lieu of the additional dewatering equipment.

Table 18 provides the opinion of annual operating cost for the five complete alternatives assuming average day annual flows from the available database used in this evaluation (2009 – 2011).

Table 18

Conceptual Opinion of O&M Cost
Annual Cost per Alternative

	Chemicals ****	Electrical* Power/Fuel	Labor & Training	Sludge** Disposal	Equip. Replace-ment	Lab & Consult	Total $
Alternative 1 Adit collection and partial Cement Creek flow treatment with mechanical solids settling and "dry" sludge disposal (1,000 gpm capacity).	$230,000	$70,000	$380,000	$150,000	$60,000	$20,000	$910,000
Alternative 2 Adit collection and partial Cement Creek flow treatment with pond settling of solids and "wet" sludge disposal (1,000 gpm capacity).	$230,000	$35,000	$380,000	$181,000	$30,000	$20,000	$876,000
Alternative 3 Cement Creek flow treatment, up to 2,000 gpm, with mechanical solids settling and "dry" sludge disposal.	$560,000	$100,000	$380,000	$280,000	$100,000	$20,000	$1,440,000
Alternative 4 Cement Creek flow treatment, up to 2,000 gpm, with pond settling of solids and "wet" sludge disposal	$560,000	$60,000	$380,000	$352,000	$50,000	$20,000	$1,422,000
Alternative 5 Adit collection and treatment with direct filtration of solids and "dry" sludge disposal (1,000 gpm capacity)	$230,000	$70,000	$380,000	$150,000	$80,000	$20,000	$930,000

* Onsite power at $0.40 kWh. Line power at $0.15 kWh

** Assumes land fill disposal (tipping fee@ $10.00/cf (2012); assumes 15 % wet settled solids from pH 9.5 and $0.09/gallon haulage cost with 2 hour round trip haul at today's fuel prices.

*** No estimate of the actual period of operation in years

**** pH/lime titration information provided in Appendix D, 375 mg/l $Ca(OH)_2$ for pH 10

8.0 COMPARISON OF ALTERNATIVES

Based upon non-financial screening criteria, alternatives 1 and 3 are superior to the others (see Table 12). Of these two, alternative 1, due to its lower annual operating costs, is financially superior.

While alternative 5 (chemical treatment and direct filtration) is a practical solution that has been used at other mining sites (i.e., Greens Creek, AK) and is very common in municipal water treatment, there is not enough seasonal solids loading data and other site specific information to recommend it without more study. Alternatives 2 and 4 (pond settling of the chemically treated target drainages) require that an acceptable disposal site for wet solids is locally available and that haulage can be done for $0.09/gallon.

9.0 CONCEPT DESIGN CRITERIA

The following presents the concept preliminary design criteria for the two alternatives considered for further discussion (Alternative 1 and 3).

Figures 2 and 3 provide schematic flow diagrams for alternatives 1 and 3 respectively. Table 19 and 20 provide the general conceptual design criteria for alternatives 1 and 3.

Table 19

Conceptual and Preliminary Design Criteria for Treatment Facilities
Alternative 1

Component	Units	Value
Influent Flow		
Maximum	gpm	1,000
Average	gpm	600±
Influent Head Tank (peak day)		
Capacity/Volume	gal	15,000
Type	---	Poly

Component	Units	Value
Influent Pumping (peak day)		
Peak Capacity	gpm	1,000
Number	No.	2
Capacity (each)	gpm	1,000
Size	HP	15
Solids Contact Clarifier (peak day)		
Chemical Feed		
Lime Pump	No.	2 (1 standby)`
Poly Pump	No.	2 (1 standby)
Static Mixer	No.	1
Reactor Vessel		
Number	No.	1
Diameter	ft	16
SWD	ft	16
Hydraulic Loading (design)	gpm/ft^2	10
Detention Time (minimum)	min	12
Thickener Clarifier		
Number	No.	1
Diameter	ft	18
SWD	ft	16
Settling Tube Loading	gpm/ft^2	8
Recycle Pumping		
Number	No.	2 (1 standby)
Capacity, each	gpm	100
% max. Influent Flow	%	5
Solids Tank		
Number	No.	1 (lined)
Size (each)	Gal	5,000
Belt Press Dewatering		
Number	No.	2
Size (width)	ft	3
Solids Target Density	%	40

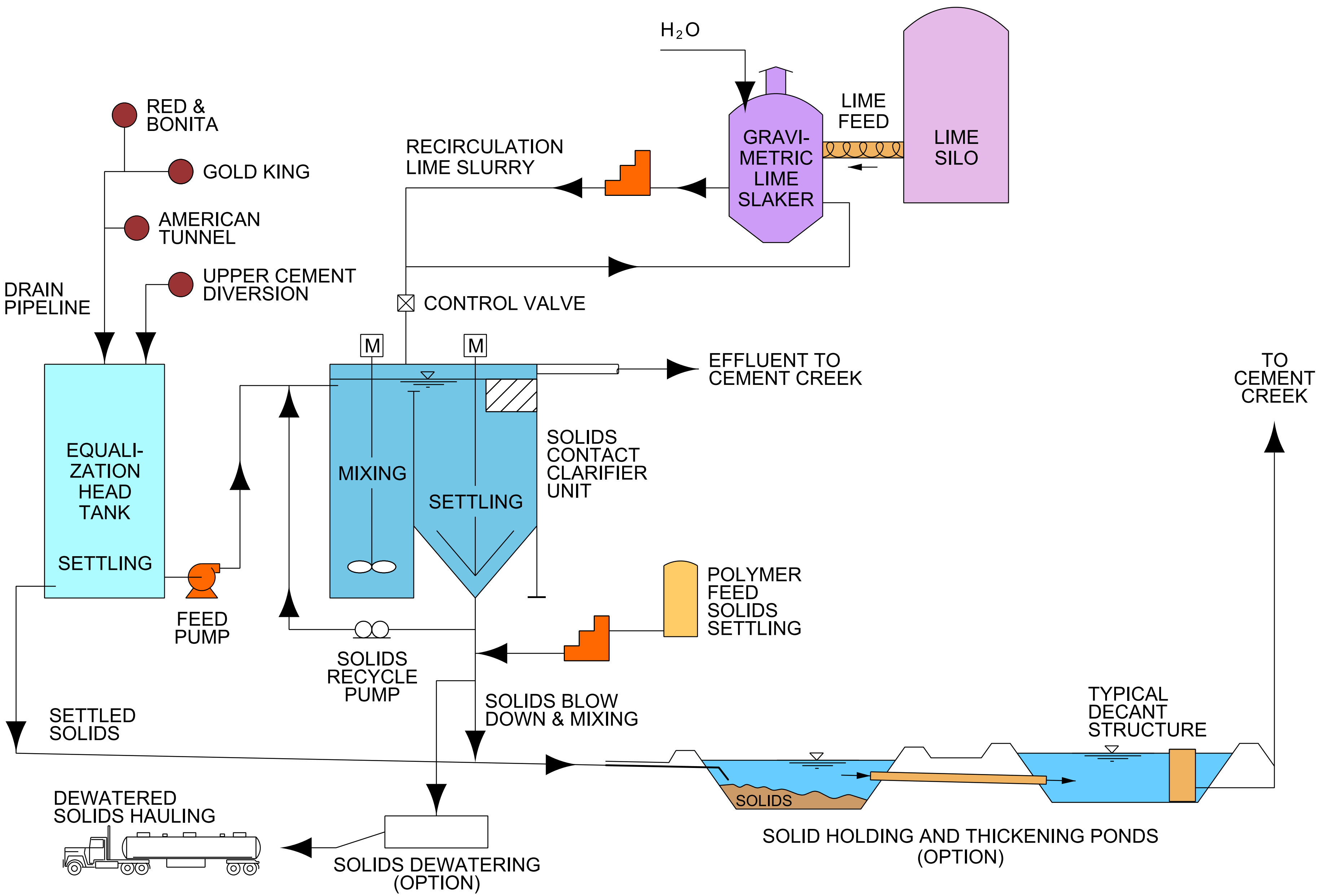

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FIGURE 2 / ALTERNATIVE 1
CONCEPTUAL SCHEMATIC DIAGRAM
MECHANICAL CHEMICAL TREATMENT (1000 GAL/MIN) AND SETTLING
ADIT DRAINAGE SITES AND UPPER CEMENT CREEK

Table 20

Conceptual and Preliminary Design Criteria for Treatment Facility Alternative 3

Component	Units	Value
Influent Flow		
Maximum	gpm	2,000
Average	gpm	1500±
Influent Head Tank (peak day)		
Capacity/Volume	gal	25,000
Type	---	Poly
Influent Pumping (peak day)		
Peak Capacity	gpm	2,000
Number	No.	3
Capacity (each)	gpm	1,000
Size	HP	15
Solids Contact Clarifier (peak day)		
Chemical Feed		
Lime Pump	No.	2 (1 standby)`
Poly Pump	No.	2 (1 standby)
Static Mixer	No.	1
Reactor Vessel		
Number	No.	1
Diameter	ft	24
SWD	ft	16
Hydraulic Loading (design)	gpm/ft^2	5
Detention Time (minimum)	min	24
Thickener Clarifier		
Number	No.	1
Diameter	ft	30
SWD	ft	16
Settling Tube Loading	gpm/ft^2	8

Component	Units	Value
Recycle Pumping		
Number	No.	2 (1 standby)
Capacity, each	gpm	100
% max. Influent Flow	%	5
Solids Tank		
Number	No.	1 (lined)
Size (each)	Gal	10,000
Belt Press Dewatering		
Number	No.	2
Size (width)	ft	6
Solids Target Density	%	40

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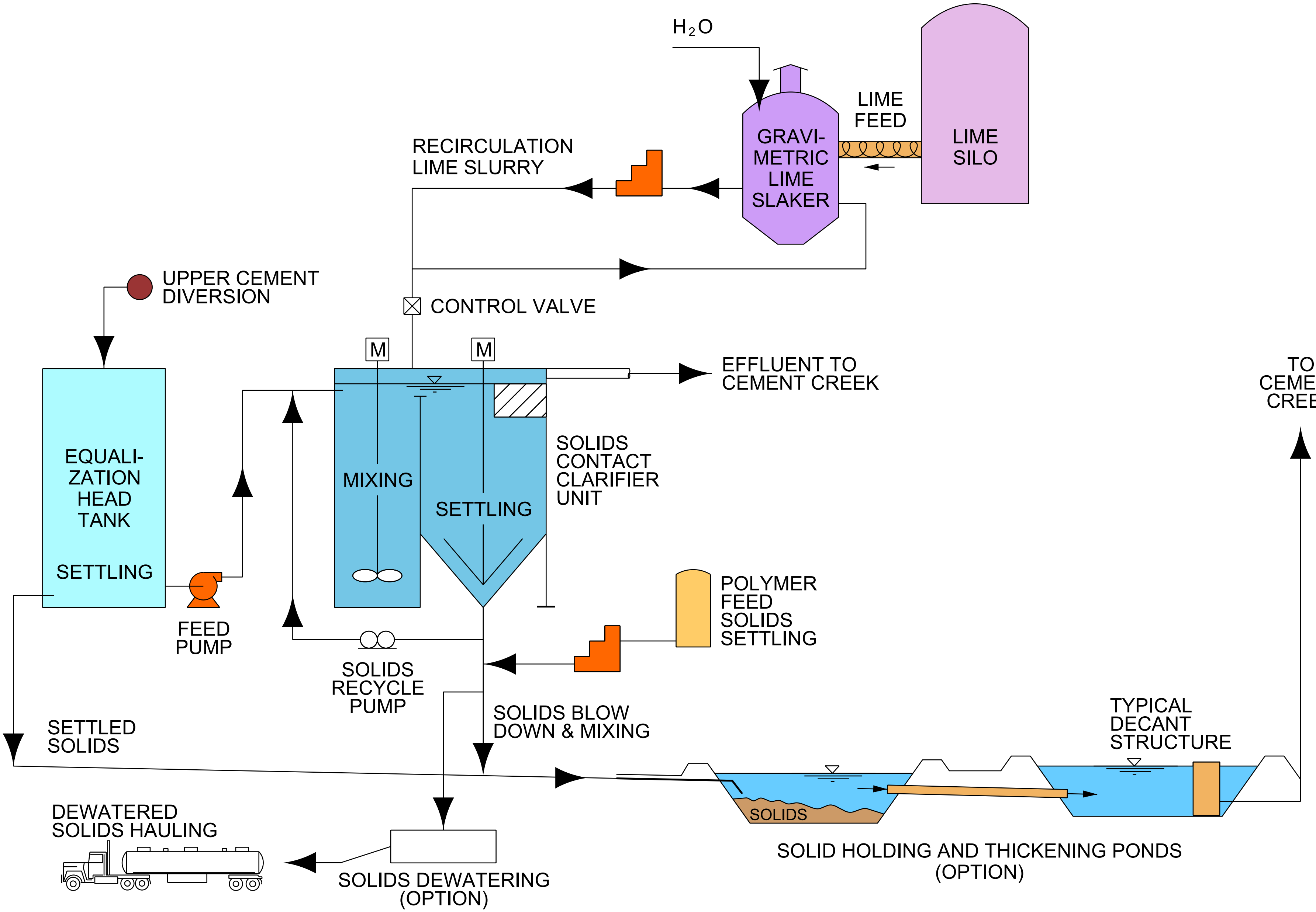

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FIGURE 3 / ALTERNATIVE 3
CONCEPTUAL SCHEMATIC DIAGRAM
MECHANICAL CHEMICAL TREATMENT (2000 GAL/MIN) AND SETTLING
UPPER CEMENT CREEK

APPENDIX A
Treatability Study

BUILDING A BETTER WORLD

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BUILDING A BETTER WORLD

TECHNICAL MEMORANDUM

TO:	Nathan Longenecker, Kevin Roach, Larry Perino, Dean Williams	DATE:	March 26, 2012
FROM:	Phil Johnson, Ed Cryer	CC:	
SUBJECT:	Upper Cement Creek Source Water Treatability Report	REF:	1012735.010101

Introduction

This technical memorandum provides the results of a bench-scale treatability study conducted on source water obtained from upper Cement Creek. The source water used in this study was collected from Cement Creek in February 2012 at monitoring station CC18 near Gladstone, downstream of the American Tunnel. Water from Cement Creek has characteristics indicative of acid rock drainage, including acidic pH and elevated levels of total dissolved solids (TDS), sulfate (SO_4), aluminum (Al), iron (Fe), and manganese (Mn). The source water also has significant levels of several dissolved constituents of concern (COCs) which include cadmium (Cd), copper (Cu), lead (Pb), and zinc (Zn).

Table 1 contains a summary of available recent (2009-2011) historic analytical results for selected constituents measured on unfiltered water from Cement Creek at CC18.

Table 1: Historic Concentration of Selected Constituents in Cement Creek Source Water (CC18)

Constituent	Units	Mean ± 1 Std. Dev.	High	Low
pH	S.U.	3.63 ± 0.16	3.86	3.24
Total Dissolved Solids (TDS)	mg/L	670 ± 251	1,100	136
Sulfate (SO_4)	mg/L	488 ± 203	963	79
Calcium (Ca)	mg/L	125 ± 53	220	12
Magnesium (Mg)	mg/L	7.9 ± 2.8	12.4	1.8
Sodium (Na)	mg/L	3.5 ± 1.3	5.8	0.5
Potassium (K)	mg/L	1.7 ± 0.6	4.0	0.5
Aluminum (Al)	mg/L	6.24 ± 2.79	9.64	1.61
Iron (Fe)	mg/L	24.9 ± 13.9	39.8	4.7
Manganese (Mn)	mg/L	23.7 ± 43.4	199.9	1.72
Cadmium (Cd)	µg/L	20.0 ± 8.8	30.1	5.1
Copper (Cu)	µg/L	608 ± 308	1,400	163
Lead (Pb)	µg/L	21.7 ± 15.9	80.4	9.6
Zinc (Zn)	µg/L	8,009 ± 4,014	12,400	1,520

Objectives of Study

The purpose of this study is to examine various chemical process options available for treatment of source water from Cement Creek. In order of importance, the following are the treatment objectives examined in this study:

1. Reduce the concentration of dissolved COCs which include Cd, Cu, Pb, and Zn.
2. Reduce the acidity of the source water by raising pH to circumneutral levels.
3. Reduce the concentration of cementitious, precipitate-forming metals in solution which include Al, Fe, and Mn.

Chemical Treatment Options

In this study, a variety of chemical treatment processes are examined based on their likelihood of satisfying one or more of the stated treatment objectives. Following is a list of the chemical treatment processes that were tested in this study on source water from Cement Creek:

1. Metal hydroxide precipitation. Addition of hydrated lime ($Ca(OH)_2$) to raise solution pH and induce precipitation of various dissolved metals (Al, Fe, Mn, Cd, Cu, Pb, Zn) as insoluble metal hydroxides (i.e., $Me(OH)_x$).
2. Enhanced coagulation. Addition of ferric chloride ($FeCl_3$) coagulant to form the mineral ferrihydrite ($Fe(OH)_3$) as precipitate, and induce co-precipitation of various dissolved metals (Al, Fe, Mn, Cd, Cu, Pb, Zn).
3. Metal sulfide precipitation. Addition of sodium bisulfide (NaHS), a soluble sulfide salt to induce precipitation of several dissolved base metals (Cd, Cu, Fe, Pb, Zn) as insoluble metal sulfide minerals (i.e., Me_xS_y).
4. Metal co-precipitation via chemical oxidation of reduced metal cations. Addition of an oxidant such as sodium hypochlorite (NaOCl) or hydrogen peroxide (H_2O_2) to oxidize ferrous iron (Fe^{2+}) and manganous manganese (Mn^{2+}) to their insoluble oxidized states to form the minerals ferrihydrite ($Fe(OH)_3$) and pyrolusite (MnO_2) as precipitates, and induce co-precipitation of various dissolved metals (Al, Fe, Mn, Cd, Cu, Pb, Zn).

Bench Testing Protocol

The bench-scale treatability study was conducted by MWH staff in the MWH Boise office. Experiments were performed using standard laboratory apparatus, glassware, instrumentation, and reagent-grade chemicals. Each experiment involved the addition of chemical reagents to a matrix of raw source water obtained from Cement Creek in February 2012 at monitoring station CC-18. Twelve separate experiments were conducted in this bench-scale treatability study.

Table 2 provides a complete list of experiments conducted in this treatability study, along with the experimental protocol and expected mineral precipitates for each experiment.

Table 2: Experimental Protocol for Bench-Scale Treatability Experiments

Chemical Process	Experiment ID	Chemical Reagents	Endpoint pH	Major Mineral Precipitates Expected
Metal Hydroxide Precipitation	1-1: Lime pH 7	$Ca(OH)_2$	7.0	$Al(OH)_3$, $Fe(OH)_3$
	1-2: Lime pH 8	$Ca(OH)_2$	8.0	$Al(OH)_3$, $Fe(OH)_3$, $Zn(OH)_2$
	1-3: Lime pH 9	$Ca(OH)_2$	9.0	$Al(OH)_3$, $Fe(OH)_3$, $Zn(OH)_2$, $Mn(OH)_2$
	1-4: Lime pH 10	$Ca(OH)_2$	10.0	$Al(OH)_3$, $Fe(OH)_3$, $Zn(OH)_2$, $Mn(OH)_2$, $Mg(OH)_2$
Enhanced Coagulation/ Co-Precipitation	2-1: 15 mg/L Fe	$Ca(OH)_2$, $FeCl_3$	8.0	$Al(OH)_3$, $Fe(OH)_3$, $Zn(OH)_2$
	2-2: 30 mg/L Fe	$Ca(OH)_2$, $FeCl_3$	8.0	$Al(OH)_3$, $Fe(OH)_3$, $Zn(OH)_2$
	2-3: 60 mg/L Fe	$Ca(OH)_2$, $FeCl_3$	8.0	$Al(OH)_3$, $Fe(OH)_3$, $Zn(OH)_2$
	2-4: 120 mg/L Fe	$Ca(OH)_2$, $FeCl_3$	8.0	$Al(OH)_3$, $Fe(OH)_3$, $Zn(OH)_2$
Metal Sulfide Precipitation	3-1: Sulfide Pre-dose	$Ca(OH)_2$, NaHS	8.0	$Al(OH)_3$, FeS_2, CuS, ZnS
	3-2: Sulfide Post-dose	$Ca(OH)_2$, NaHS	8.0	$Al(OH)_3$, FeS_2, CuS, ZnS
Metal Oxidation/ Co-Precipitation	4-1: Hypochlorite	$Ca(OH)_2$, NaOCl	8.0	$Al(OH)_3$, $Fe(OH)_3$, $Zn(OH)_2$, MnO_2
	4-2: Peroxide	$Ca(OH)_2$, H_2O_2	8.0	$Al(OH)_3$, $Fe(OH)_3$, $Zn(OH)_2$, MnO_2

Experimental Procedure

Chemical reagents were added to the source water while mixing the solution on a magnetic stir plate. During mixing, instrumentation was used to monitor solution pH, oxidation-reduction potential (ORP), and turbidity. After sufficient mixing and chemical addition to reach the targeted endpoint conditions, the mix solution was transferred to a settleometer for determination of settling characteristics.

After 10 minutes of settling under quiescent conditions, the solids volume fraction and supernate turbidity were determined and the sample was transferred to vacuum filtration apparatus and filtered through 0.45-µm filter paper. Filtrate obtained from each experiment was collected in sample bottles and shipped to a contract lab (SVL Laboratories, Kellogg, ID) for analysis. Table 3 provides the analytical methods, method detection limits, and reporting limits for the list of analytes measured at the contract lab.

Filter paper containing residual solids from each experiment was dewatered using vacuum filtration apparatus and weighed on an analytical balance to determine wet solids. The wet solids samples were then air-dried overnight and re-weighed to determine dry solids.

Lime Addition Experiments. Four separate experiments were conducted using hydrated lime ($Ca(OH)_2$) to raise the pH of the source water to induce precipitation of metal hydroxides. Separate endpoint pH values of 7, 8, 9, and 10 were targeted in the four experiments. In the first experiment, raising the source water pH from its initial value of 3 to an endpoint value of 7 is only expected to generate $Al(OH)_3$ and $Fe(OH)_3$ as mineral precipitates. Stepwise increases in the endpoint pH in subsequent experiments result in additional metal hydroxides precipitating from solution so that for an endpoint pH of 10, the list of major mineral precipitates is expected to include $Al(OH)_3$, $Fe(OH)_3$, $Zn(OH)_2$, $Mn(OH)_2$, and $Mg(OH)_2$. Along with the major mineral precipitates expected in the lime addition experiments, other COCs not included in the list of minerals are expected to undergo varying degrees of removal from solution as co-precipitates of the major mineral phases.

Coagulant Addition Experiments. Four separate experiments were conducted using ferric chloride ($FeCl_3$) as a chemical coagulant. Coagulant doses of 15, 30, 60, and 120 mg/L as Fe were used in this group of experiments. After addition of coagulant, hydrated lime was added to the mix to raise the pH to an endpoint value of 8. The main minerals that are expected to precipitate in each of the coagulation experiments are $Al(OH)_3$, $Fe(OH)_3$, and $Zn(OH)_2$. Along with the major mineral precipitates expected in the coagulation experiments, other COCs not included in the list of minerals are expected to undergo varying degrees of removal from solution as co-precipitates of the major mineral phases.

Table 3: List of Analytes and Analytical Methods

Analyte	Analytical Method	Reporting Limit (mg/L)	Method Detection Limit (mg/L)
Total Dissolved Solids (TDS)	SM 2540C	10	2
Sulfate (SO_4)	EPA 300.0	15.0	1.95
Chloride (Cl)	EPA 300.0	0.20	0.07
Fluoride (F)	EPA 300.0	0.50	0.11
Sodium (Na)	EPA 200.7	0.50	0.04
Potassium (K)	EPA 200.7	0.50	0.07
Magnesium (Mg)	EPA 200.7	0.060	0.021
Calcium (Ca)	EPA 200.7	0.040	0.012
Aluminum (Al)	EPA 200.7	0.080	0.016
Silica (SiO_2)	EPA 200.7	0.17	0.06
Iron (Fe)	EPA 200.7	0.060	0.017
Manganese (Mn)	EPA 200.7	0.0040	0.0011
Arsenic (As)	EPA 200.8	0.0030	0.0002
Antimony (Sb)	EPA 200.8	0.00300	0.00012
Selenium (Se)	EPA 200.8	0.00300	0.00022
Strontium (Sr)	EPA 200.8	0.0050	0.0004
Barium (Ba)	EPA 200.8	0.00100	0.000011
Beryllium (Be)	EPA 200.8	0.00020	0.000077
Cadmium (Cd)	EPA 200.8	0.00020	0.000013
Cobalt (Co)	EPA 200.8	0.00100	0.000029
Copper (Cu)	EPA 200.8	0.00100	0.000072
Lead (Pb)	EPA 200.8	0.00300	0.000013
Nickel (Ni)	EPA 200.8	0.00100	0.00032
Zinc (Zn)	EPA 200.8	0.0050	0.0008

Sulfide Addition Experiments. Two separate experiments were conducted using sodium bisulfide (NaHS) as a soluble sulfide salt to test the feasibility of precipitating the COCs as metal sulfides. In the first experiment, sulfide was pre-dosed to the raw source water and allowed to react at low pH before addition of hydrated lime to raise the pH to an endpoint value of 8. In the second experiment, the solution pH was increased from an initial value of 3 to an intermediate value of 6 before addition of sulfide. The main minerals that are expected to precipitate in each of the sulfide experiments are $Al(OH)_3$, FeS_2, CuS, and ZnS. Minor amounts of CdS, PbS, MnS, and NiS are also expected to form mineral precipitates in the sulfide addition experiments.

Oxidant Addition Experiments. Two separate experiments were conducted using sodium hypochlorite (NaOCl) and hydrogen peroxide (H_2O_2) as oxidants. The objective of the oxidation experiments is to induce precipitation of reduced metals in solution by converting them to a higher oxidation state where they have much lower solubility. The reduced metals dissolved in the source water that experience precipitation at a higher oxidation state are ferrous iron (Fe^{2+}) and manganous manganese (Mn^{2+}). Oxidation of ferrous iron to ferric iron (Fe^{3+}) induces precipitation of iron as the mineral ferrihydrite ($Fe(OH)_3$). Oxidation of manganous manganese to manganic manganese (Mn^{4+}) induces precipitation of manganese as the mineral pyrolusite (MnO_2). After addition of oxidant, the endpoint pH of the mix solution was raised to 8 by addition of hydrated lime. The main mineral precipitates that are expected for the oxidation experiments are $Al(OH)_3$, $Fe(OH)_3$, $Zn(OH)_2$, and MnO_2. Along with the major mineral precipitates expected in the oxidation experiments, other COCs not included in the list are expected to undergo varying degrees of removal from solution as co-precipitates of the major mineral phases.

Experimental Results

Experimental Observations

The experimental record of process control variables and observations collected during the bench tests are provided in **Table 4**. Photographs of the individual experiments may be found in **Appendix 1**.

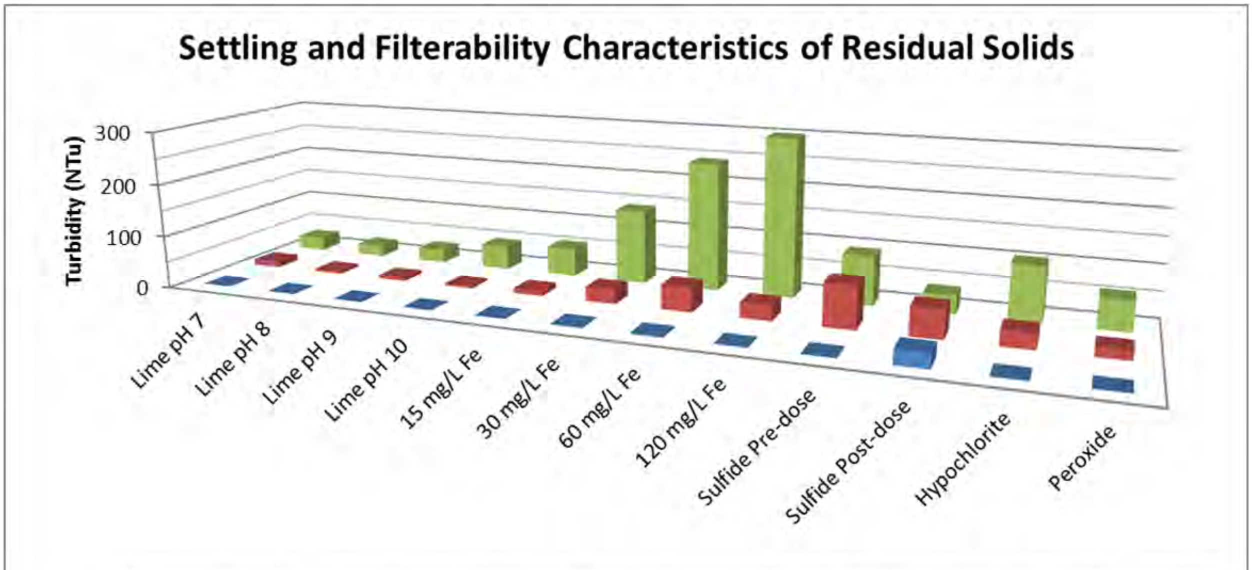
Table 4: Experimental Observations and Process Control Parameter Record

Experiment ID	Mix			10 Minute Settling		Filtrate			Precipitate	
	pH	ORP (mV)	Turbidity (NTU)	Solids Volume Fraction	Supernate Turbidity (NTU)	pH	ORP (mV)	Turbidity (NTU)	Wet Solids (mg/L)	Dry Solids (mg/L)
1-1: Lime pH 7	7.12	322	26.5	0.027	11.7	6.88	308	0.42	603	91
1-2: Lime pH 8	8.06	269	21.4	0.027	5.79	7.47	253	0.41	871	116
1-3: Lime pH 9	9.03	150	25.9	0.041	6.38	8.75	166	0.56	912	131
1-4: Lime pH 10	10.02	68	45.9	0.054	4.39	9.80	104	0.40	1206	177
2-1: 15 mg/L Fe	8.10	220	54.4	0.041	10.3	7.83	248	1.36	992	133
2-2: 30 mg/L Fe	8.38	196	141	0.041	27.6	7.85	258	2.46	1464	189
2-3: 60 mg/L Fe	8.29	198	243	0.053	46.5	8.13	211	2.52	1892	278
2-4: 120 mg/L Fe	8.19	207	302	0.104	29.5	7.07	232	0.64	3190	421
3-1: Sulfide Pre-dose	8.04	-207	93.5	0.014	80.9	7.17	-47	1.42	576	119
3-2: Sulfide Post-dose	9.25	-280	36.1	0.041	54.2	8.95	169	27.5	833	150
4-1: Hypochlorite	8.06	544	104	0.040	30.2	7.91	809	1.46	1127	167
4-2: Peroxide	8.23	247	57.7	0.040	17.2	7.12	266	0.48	943	157

Residual Solids Characteristics

The experimental observations provide useful information about the settleability, filterability, and mass of residual solids generated by each chemical treatment process.

Figure 1 provides a graphical summary of the settleability, filterability, and amount of residual solids generated in each experiment. In the figure, the mix turbidity provides a semi-quantitative measure of the amount of solids generated, while the supernate turbidity recorded after 10 minutes of settling provides a qualitative measurement of solids settleability for each chemical treatment option. The figure also provides a record of filtrate turbidity for 0.45 µm filter paper, which is a qualitative measure of filterability as well as a semi-quantitative measure of particle size for residual solids.



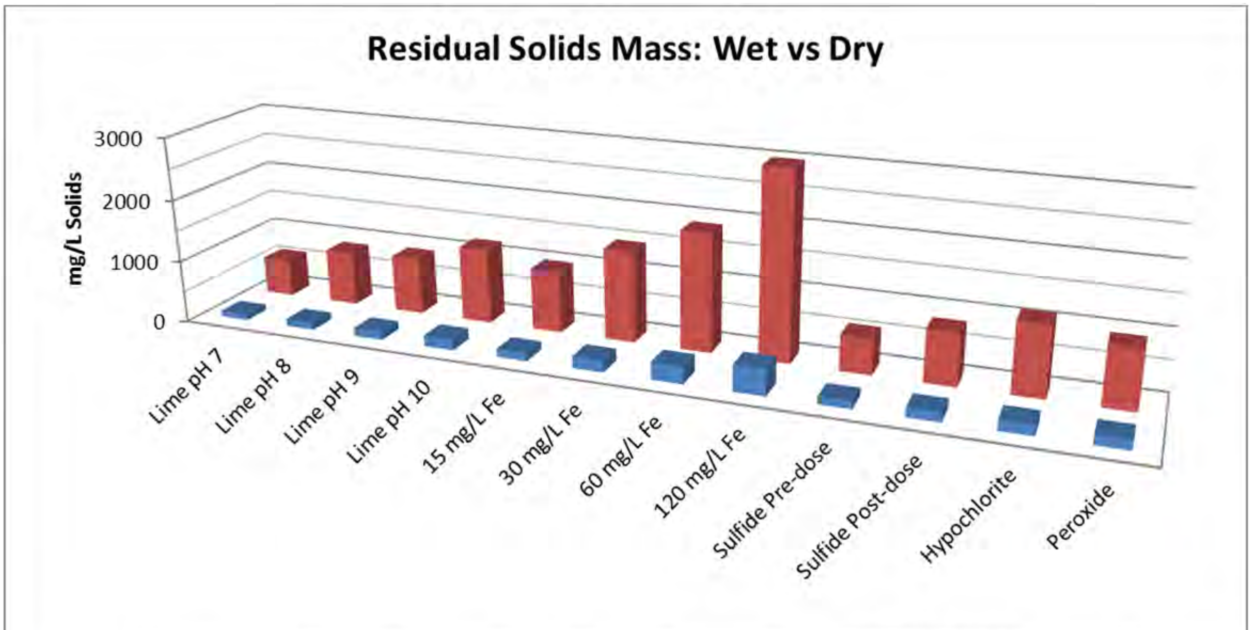
	Lime pH 7	Lime pH 8	Lime pH 9	Lime pH 10	15 mg/L Fe	30 mg/L Fe	60 mg/L Fe	120 mg/L Fe	Sulfide Pre-dose	Sulfide Post-dose	Hypochlorite	Peroxide
Filtrate	0.42	0.41	0.56	0.40	1.36	2.46	2.52	0.64	1.42	27.5	1.46	0.48
Supernate	11.7	5.79	6.38	4.39	10.3	27.6	46.5	29.5	80.9	54.2	30.2	17.2
Mix	26.5	21.4	25.9	45.9	54.4	141	243	302	93.5	36.1	104	57.7

Figure 1: Residual Solids 10-Minute Settling and 0.45 µm Filterability Characteristics

The filtrate turbidity results using 0.45 µm filter paper suggest that each of the treatment processes examined will generate residual solids having filterable particle sizes, with the exception of treatment with a post-pH adjustment dose of sulfide. For the sulfide post-dose experiment, filtrate turbidity was measured at 27.5 NTU while filtrate from the other experiments had significantly lower turbidities of between 0.40 NTU and 2.52 NTU. This result for the sulfide post-dose experiment suggests that this chemical process is not a viable treatment option for source water from Cement Creek since a major fraction of the residual solids would remain in suspension following both clarification and filtration.

The 10-minute settling results for supernate turbidity suggest that pH adjustment with lime produces the fastest settling solids, followed in descending order by oxidation, coagulation, and sulfide addition. There is a weak trend in the lime experiments indicating that settling rate increases with increasing pH, where the supernate turbidity is highest at pH 7 and lowest at pH 10 (i.e., 11.7 NTU vs 4.39 NTU). The settling rates of the Fe coagulation experiments show a steady decrease from 15 mg/L Fe to 60 mg/L Fe (10.3 NTU to 46.5 NTU), followed by a significant increase in settleability with an increase in coagulant dose from 60 mg/L to 120 mg/L (46.5 NTU vs 29.5 NTU). For the sulfide precipitation experiments, the post-dose experiment produces a faster settling rate than the pre-dose experiment (54.2 NTU vs 80.9 NTU). For the oxidation experiments, hydrogen peroxide precipitate settles faster than sodium hypochlorite precipitate (17.2 NTU vs 30.2 NTU).

Figure 2 provides a graphical summary of the residual solids mass generated for each experiment. In the figure, both wet and dry solids are plotted to provide a visual indication of the amount of residual solids that can be expected for each chemical treatment option.



	Lime pH 7	Lime pH 8	Lime pH 9	Lime pH 10	15 mg/L Fe	30 mg/L Fe	60 mg/L Fe	120 mg/L Fe	Sulfide Pre-dose	Sulfide Post-dose	Hypochlorite	Peroxide
Dry Solids	91	116	131	177	133	189	278	421	119	150	167	157
Wet Solids	603	871	912	1206	992	1464	1892	3190	576	833	1127	943

Figure 2: Comparison of Wet and Dry Residual Solids Mass

As expected, Fe coagulation generated the greatest amount of wet solids, followed in descending order by oxidation, lime precipitation, and sulfide precipitation. The same order is evident for dry solids, although the magnitude of difference is significantly attenuated. This suggests that solids generated by Fe coagulation may have better dewatering characteristics than the other chemical treatment processes examined in this study.

Analytical Results

Table 5 contains the analytical results from the contract lab for filtered water from the twelve bench-scale experiments, along with an analysis of filtered source water from Cement Creek.

Table 5: Analytical Results of Bench-Scale Experiments

Analyte (mg/L)	Source Water	Experiment 1-1: Lime pH 7	Experiment 1-2: Lime pH 8	Experiment 1-3: Lime pH 9	Experiment 1-4: Lime pH 10	Experiment 2-1: 15 mg/L Fe	Experiment 2-2: 30 mg/L Fe	Experiment 2-3: 60 mg/L Fe	Experiment 2-4: 120 mg/L Fe	Experiment 3-1: Sulfide Pre-dose	Experiment 3-2: Sulfide Post-dose	Experiment 4-1: Hypochlorite	Experiment 4-2: Peroxide
TDS	1,540	1,540	1,540	1,530	1,550	1,600	1,630	1,730	1,890	1,590	1,570	1,650	1,530
SO_4	1,050	1,020	1,030	1,020	1,020	1,030	1,030	1,020	987	1,010	1,040	1,020	1,030
Cl	0.25	1.01	0.74	0.72	0.59	27.7	62.4	112	236	9.98	0.77	79.7	2.14
F	4.27	3.81	4.07	4.10	3.91	3.86	4.83	3.94	3.56	3.95	4.06	3.50	3.94
Na	7.10	6.91	7.06	6.99	6.96	7.18	7.24	6.94	6.92	49.3	49.1	78.9	7.20
K	1.43	1.73	1.79	1.56	1.58	2.16	1.59	1.55	1.55	2.06	1.82	2.26	3.61
Mg	22.0	21.4	21.6	21.4	19.3	21.7	21.0	20.9	21.1	21.7	21.3	21.2	20.8
Ca	336	378	390	399	417	416	446	462	537	362	369	400	398
Al	8.99	ND	ND	0.086	0.538	ND	0.098	0.121	ND	0.095	ND	ND	0.095
SiO_2	38.8	25.0	20.2	14.8	6.96	16.3	9.86	5.66	3.21	24.4	17.1	21.4	15.3
Fe	6.18	ND	ND	ND	ND	ND	ND	ND	ND	0.176	ND	ND	ND
Mn	25.4	23.3	25.3	16.4	0.258	20.2	12.6	10.4	6.40	23.4	15.4	0.0405	4.86
As	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND
Sb	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND
Se	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND
Sr	3.59	3.53	3.54	3.54	3.54	3.56	3.61	3.47	3.51	3.50	3.44	3.46	3.50
Ba	0.0260	0.0309	0.0244	0.0179	0.0158	0.0255	0.0192	0.0133	0.0110	0.0141	0.0209	0.0056	0.0136
Be	0.00379	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND
Cd	0.0298	0.0237	0.0133	0.0021	ND	0.0092	0.0024	0.0015	0.0005	ND	ND	0.0006	0.0015
Co	0.0769	0.0704	0.0596	0.0238	0.0012	0.0514	0.0217	0.0124	0.0077	0.0115	0.0163	0.0013	0.0201
Cu	0.417	0.0053	0.0022	0.0013	0.0010	0.0014	0.0013	0.0011	ND	0.0015	0.0018	0.0024	0.0012
Pb	0.0511	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND
Ni	0.0478	0.0436	0.0379	0.0243	0.0098	0.0369	0.0244	0.0203	0.0187	0.0252	0.0358	0.0134	0.0246
Zn	13.3	6.17	0.925	0.0386	0.0061	0.737	0.171	0.0801	0.0476	0.0134	0.0413	0.171	0.163

Table 5 General Notes:
ND = not detected

Experimental Observations and Analytical Results for Source Water from Cement Creek. The Cement Creek source water used in this study has the following characteristics:

- pH = 3.07
- ORP = 621 mV
- Turbidity, unfiltered = 53.5 NTU
- Turbidity, filtered = 0.68 NTU
- Color, unfiltered: rusty red
- Color, filtered: colorless
- TDS = 1,540 mg/L
- Fe = 6.18 mg/L

An examination of these parameters suggests that the source water is well aerated, as evidenced by the high ORP value of 621 mV. The low Fe concentration reported in the analysis combined with the elevated ORP indicates that all iron in the source water is present as oxidized ferric iron (Fe^{3+}). At a pH value of 3, ferric iron remains soluble up to a concentration of about 2 mg/L. Thus, the high turbidity noted for the unfiltered source water is likely due to precipitated iron as the mineral ferrihydrite ($Fe(OH)_3$).

Comparison of Analytical Results with Water Quality Criteria. In order to determine whether the chemical treatment processes examined in this report are effective for removing COCs from the Cement Creek source water, Table 6 is provided as a comparison of water quality criteria and analytical results for selected COCs.

For the cementitious metal COCs (Al and Fe), the source water contains dissolved concentrations of both constituents that exceed their respective aquatic water quality standards. Chemical treatment options that fail to meet the Al standard are lime pH 10, 30 mg/L Fe, 60 mg/L Fe, sulfide pre-dose, and peroxide. All of the treatment options satisfy the Fe standard.

For the metalloids (As, Sb, and Se), the source water has dissolved concentrations of all three constituents that are below their respective method detection limits. Each of the experiments also has dissolved concentrations of the three metalloids that are below their respective method detection limits.

For beryllium (Be), the source water has a measureable concentration of 0.0037 mg/L which is slightly less than the drinking water quality standard of 0.004 mg/L. All of the treatment options satisfy the Be standard, with measurements below the method detection limit.

For the heavy metals (Cd, Cu, Pb, Ni, and Zn), all of the constituents except Ni have dissolved concentrations in the source water that exceed their respective water quality standards. Experiments that exceed the Cd standard are lime pH 7, lime pH 8, 15 mg/L Fe, and 30 mg/L Fe. All of the treatment options satisfy the respective standards for Cu, Pb, and Ni. Experiments that exceed the Zn standards are lime pH 7, lime pH 8, and 15 mg/L Fe.

Each of the four chemical treatment processes has one experiment that satisfies all of the water quality standards for the listed COCs shown in Table 6. For lime precipitation, adjusting the source water pH from 3 to 9 produces the best results. For coagulation at pH 8, addition of 120 mg/L Fe produces the best results. For sulfide precipitation at pH 8, adding the sulfide after the pH adjustment produces better water quality than addition of sulfide before pH adjustment. For oxidant addition at pH 8, sodium hypochlorite produces better water quality than hydrogen peroxide addition.

Table 6: Comparison of Water Quality Criteria and Analytical Results for Selected COCs

Analyte (mg/L)	Al	Fe	As	Sb	Se	Be	Cd	Cu	Pb	Ni	Zn
Primary Drinking Water Standard	-	-	0.010	0.006	0.05	0.004	0.005	1.3[a]	0.015[a]	-	-
Freshwater Aquatic Life/Acute	0.750[b]	-	0.340	-	-	-	0.0073[c]	0.0547[c]	0.1885[c]	1.069[c]	0.3314[c]
Freshwater Aquatic Life/Chronic	0.087[b]	1.00	0.150	-	0.005	-	0.0022[c]	0.0375[c]	0.0030[c]	0.1665[c]	0.3341[c]
Cement Creek Source Water	8.99	6.18	ND	ND	ND	0.0037	0.0298	0.417	0.0511	0.0478	13.3
Experiment 1-1: Lime pH 7	ND	ND	ND	ND	ND	ND	0.0237	0.0053	ND	0.0436	6.17
Experiment 1-2: Lime pH 8	ND	ND	ND	ND	ND	ND	0.0133	0.0022	ND	0.0379	0.925
Experiment 1-3: Lime pH 9	0.086	ND	ND	ND	ND	ND	0.0021	0.0013	ND	0.0243	0.0386
Experiment 1-4: Lime pH 10	0.538	ND	ND	ND	ND	ND	ND	0.0010	ND	0.0098	0.0061
Experiment 2-1: 15 mg/L Fe	ND	ND	ND	ND	ND	ND	0.0092	0.0014	ND	0.0369	0.737
Experiment 2-2: 30 mg/L Fe	0.098	ND	ND	ND	ND	ND	0.0024	0.0013	ND	0.0244	0.171
Experiment 2-3: 60 mg/L Fe	0.121	ND	ND	ND	ND	ND	0.0015	0.0011	ND	0.0203	0.0801
Experiment 2-4: 120 mg/L Fe	ND	ND	ND	ND	ND	ND	0.0005	ND	ND	0.0187	0.0476
Experiment 3-1: Sulfide Pre-dose	0.095	0.176	ND	ND	ND	ND	ND	0.0015	ND	0.0252	0.0134
Experiment 3-2: Sulfide Post-dose	ND	ND	ND	ND	ND	ND	ND	0.0018	ND	0.0358	0.0413
Experiment 4-1: Hypochlorite	ND	ND	ND	ND	ND	ND	0.0006	0.0024	ND	0.0134	0.171
Experiment 4-2: Peroxide	0.095	ND	ND	ND	ND	ND	0.0015	0.0012	ND	0.0246	0.163

Table 6 General Notes:
ND = not detected
Water quality standards shown in BLUE are the lowest value for a given COC and thus represent the governing standard
Analyte values shown in RED exceed one or more of the water quality standards

Table 6 Footnotes:
a. Action level
b. Aluminum water quality criterion for total recoverable metal and pH range of 6.5 to 9
c. Water quality standard for this metal is expressed as a function of 400 mg/L hardness in the water column

Recommended Chemical Treatment Alternatives

Source Water Treatment Objectives

The experimental observations and analytical results of this bench-scale treatability study indicate that chemical treatment of source water from Cement Creek is required in order to satisfy the following water quality objectives:

- Raise the solution pH from the acidic range (pH = 3) to the circumneutral range (pH = 6.5 to 9).
- Produce a clarified final effluent that has low turbidity (< 30 NTu).
- Reduce the level of cementitious metals (Al, Mn, and Fe) that are dissolved in the source water.
- Reduce the concentration of heavy metals (Cd, Cu, Pb, and Zn) to levels that satisfy water quality standards.

Effectiveness of Chemical Treatment Options

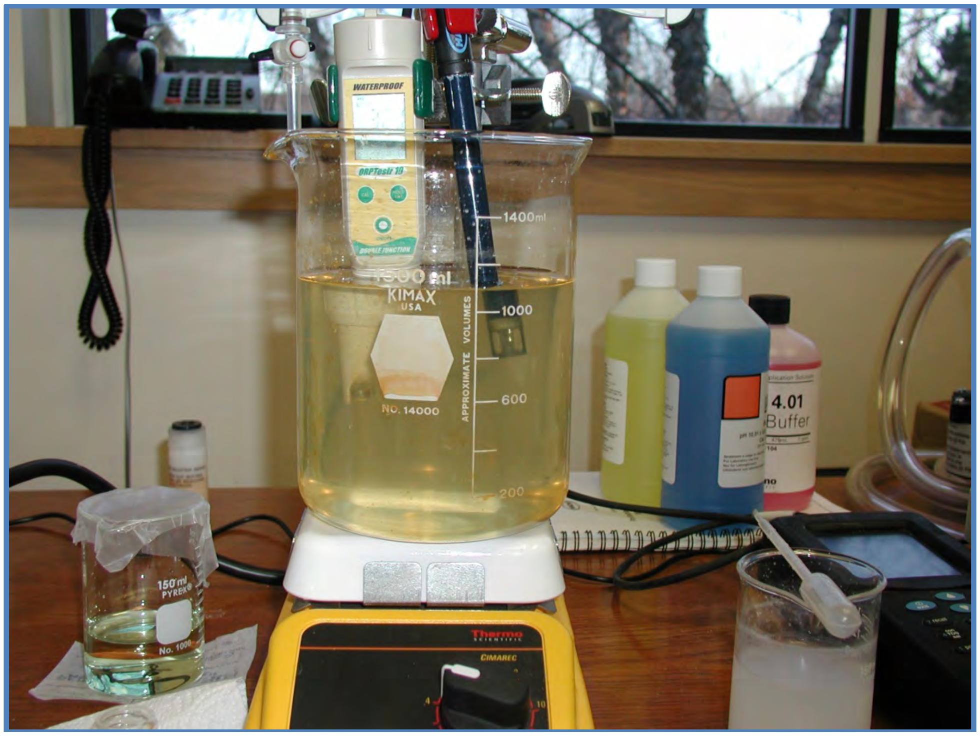
The chemical treatment options examined in this study that best satisfy the stated treatment objectives for Cement Creek source water are the following:

1. Hydrated lime addition to raise pH from 3 to 9.
2. Sodium bisulfide addition prior to hydrated lime addition to raise pH from 3 to 8.
3. Sodium hypochlorite addition following hydrated lime addition to raise pH from 3 to 8.

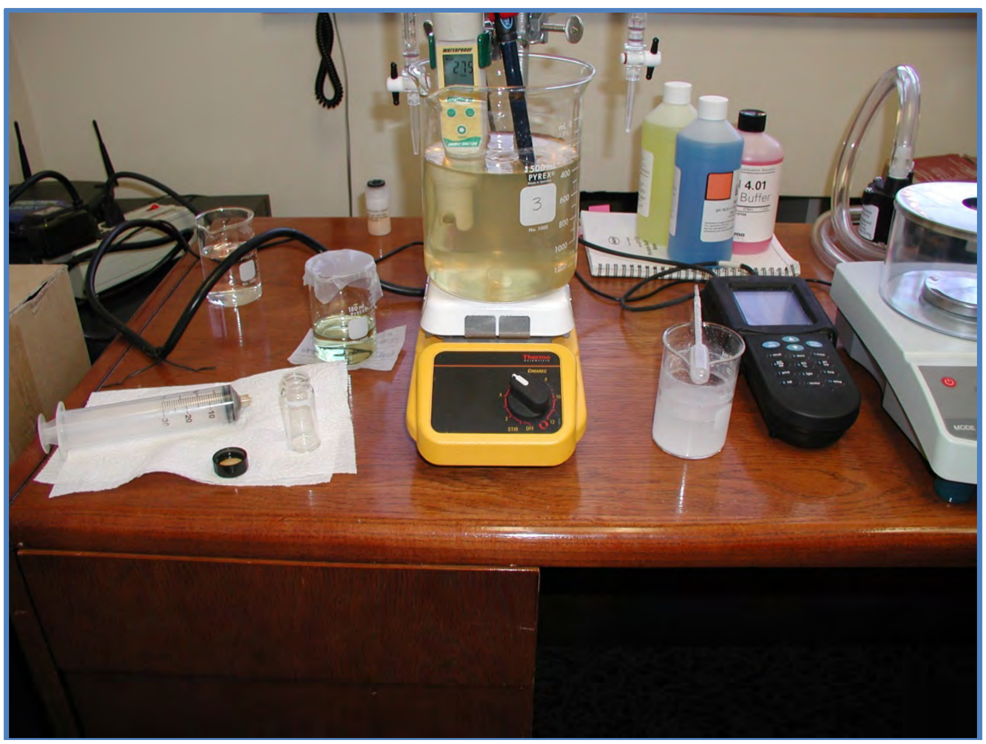
The other chemical treatment options involving enhanced coagulation with iron, post-sulfide addition, and oxidation with hydrogen peroxide are not recommended for the following reasons:

- Enhanced coagulation using ferric chloride requires coagulant doses of more than 60 mg/L Fe to achieve the water quality standards for Al and Cd. Such high coagulant doses will result in excessive operation and maintenance costs associated with chemical purchases and residual solids handling/disposal.
- Post-pH adjustment addition of sodium bisulfide for base metal precipitation is unlikely to produce a clarified effluent that has turbidity less than 30 NTu.
- Oxidation with hydrogen peroxide is much less effective than sodium hypochlorite for removal of the cementitious metals Al and Mn.

Cement Creek Source Water Bench-Scale Testing

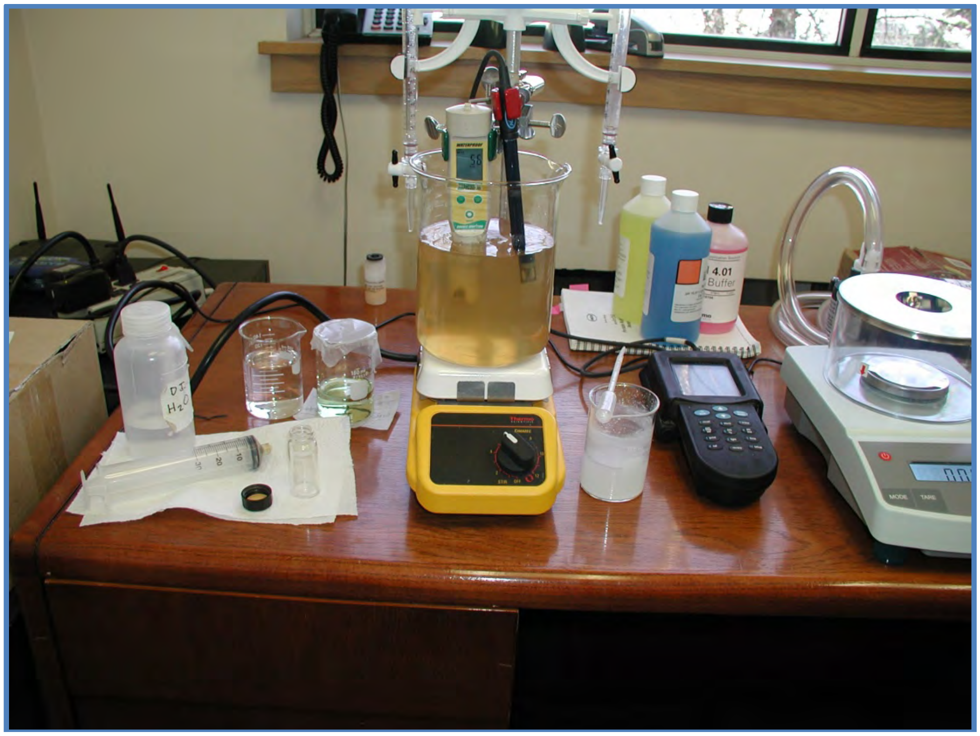


Lime pH 7



Lime pH 8

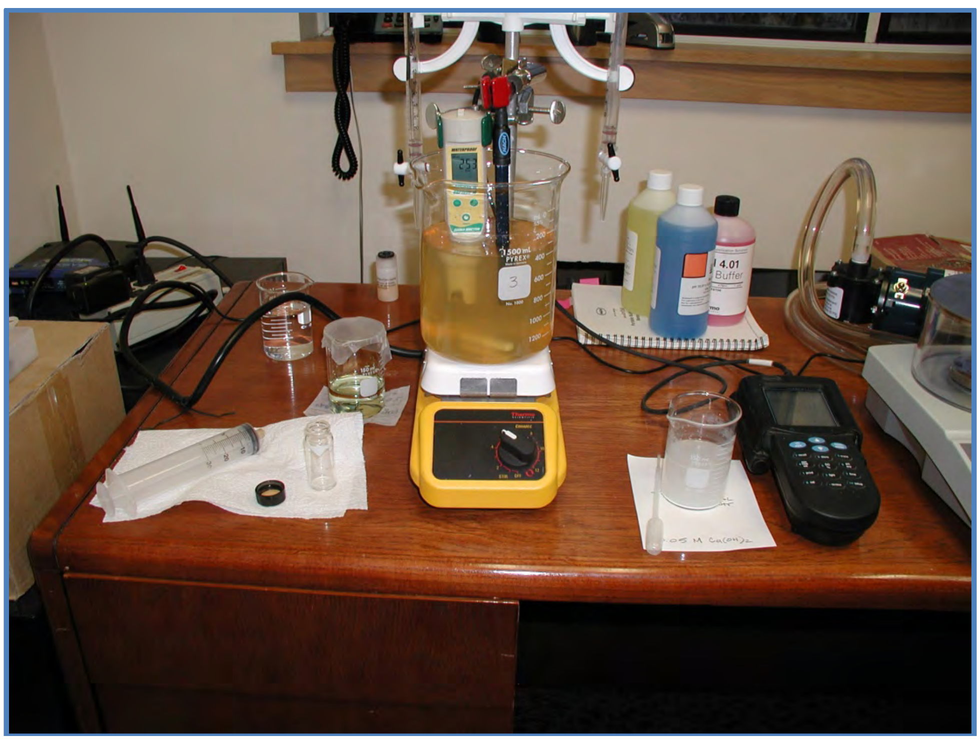
Lime pH 9



Lime pH 10

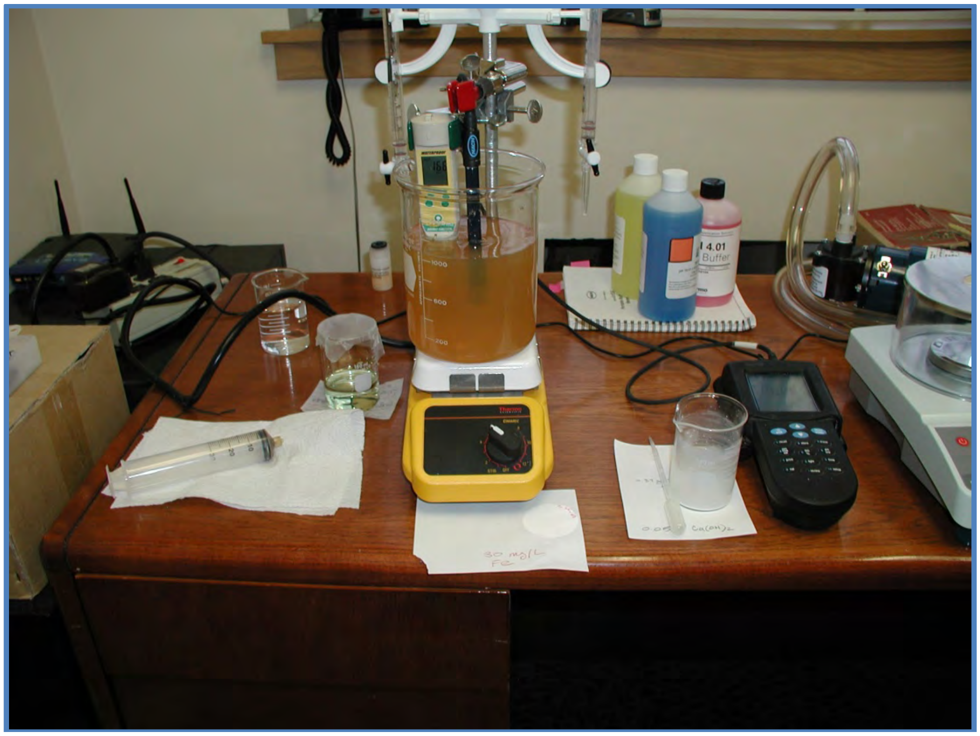
Cement Creek Source Water Bench-Scale Testing

Filtered Solids – Lime
pH 7, 8, 9, 10 (L to R)

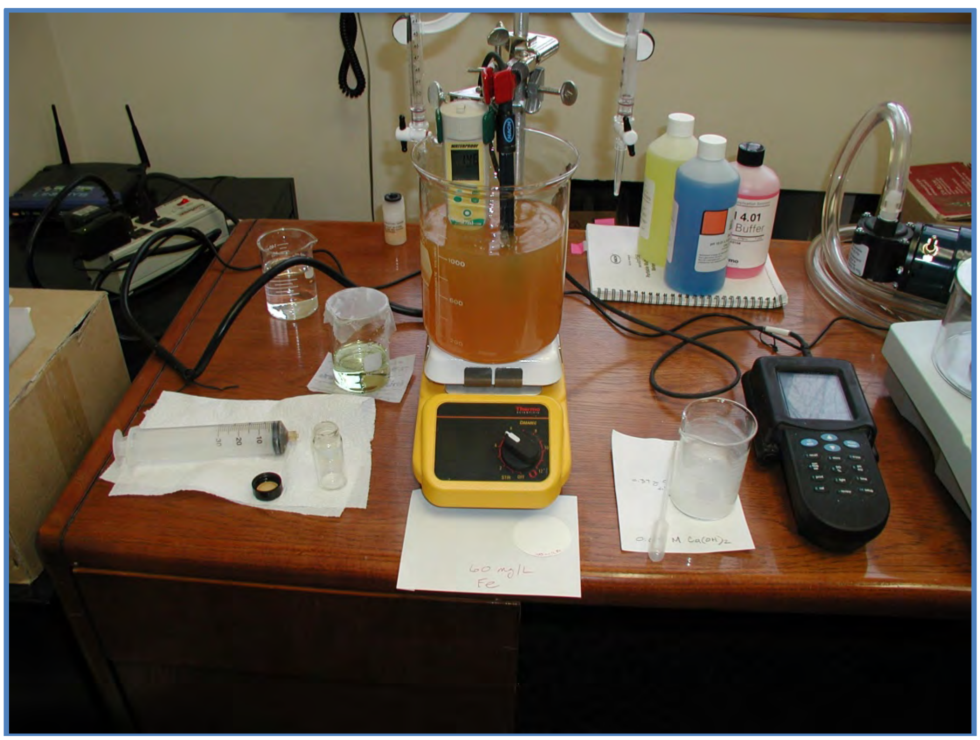


15 mg/L Fe Coagulant

Cement Creek Source Water Bench-Scale Testing



30 mg/L Fe Coagulant



60 mg/L Fe Coagulant

Cement Creek Source Water Bench-Scale Testing

120 mg/L Fe Coagulant

Filtered Solids – Fe Coagulant/Wet
15, 30, 60, 120 mg/L (L to R)

Cement Creek Source Water Bench-Scale Testing

Filtered Solids – Fe Coagulant/Dry
15, 30, 60, 120 mg/L (L to R)

Pre-dose Sulfide

Cement Creek Source Water Bench-Scale Testing

Post-dose Sulfide

Hypochlorite

Cement Creek Source Water Bench-Scale Testing

Filtered Solids: Sulfide (top) / Oxidant (bottom)

APPENDIX B
Line Use vs. pH

MWH®

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Cement Creek
pH Control Using Lime
(titration)

pH	**mg/L Ca (OH_2)**
6	182
7	216
8	251
9	275
10	374

Titration was performed during development of bench scale evaluation using the February 2012 water sample from Cement Creek from CC-48.

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